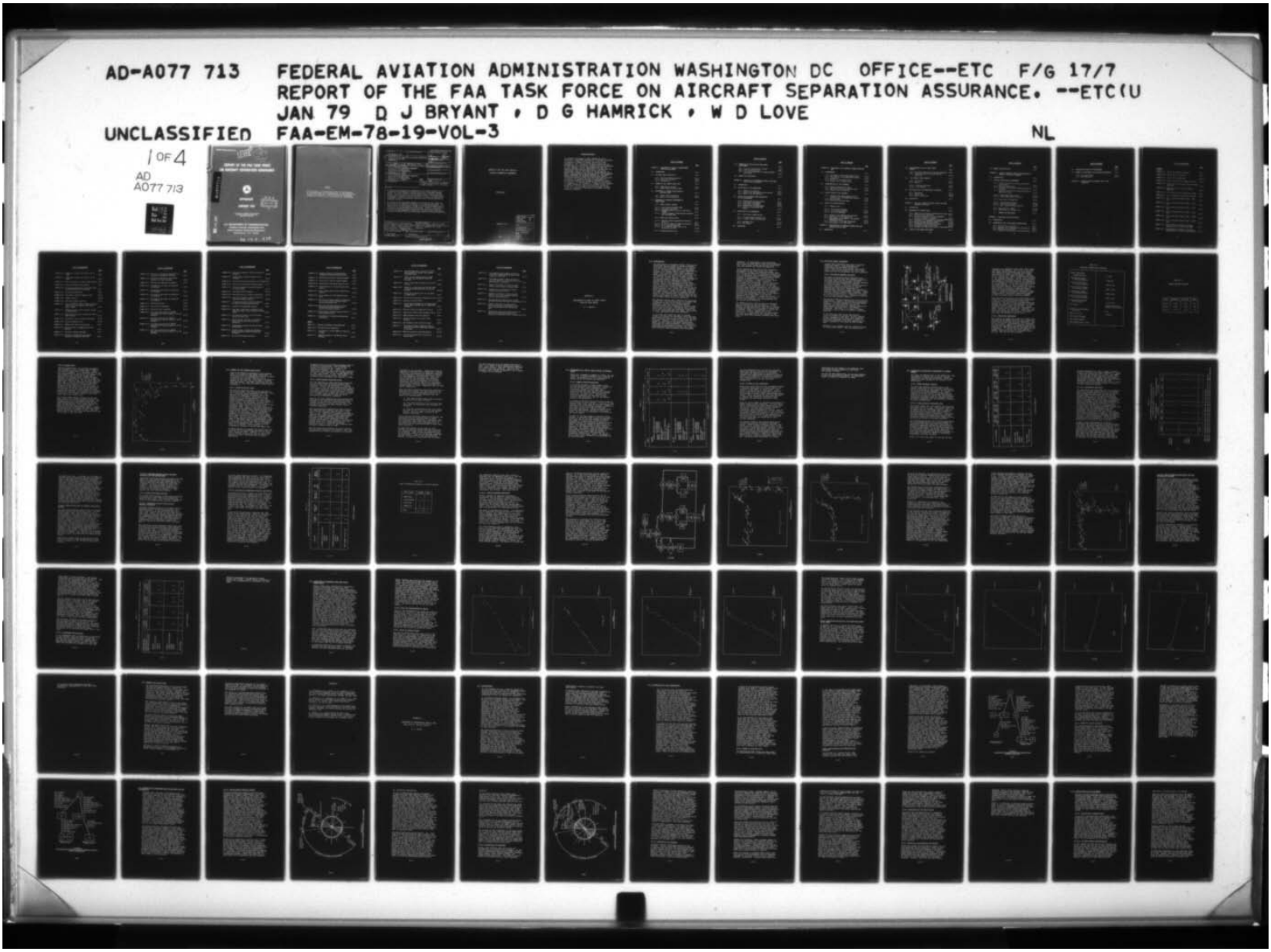
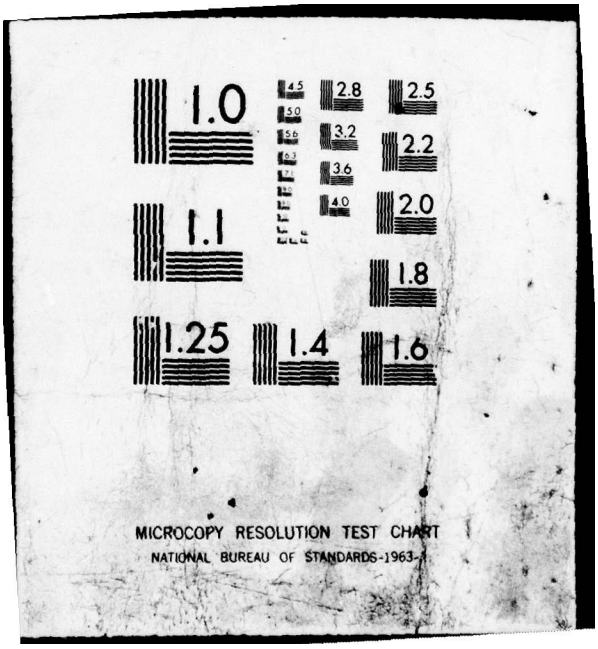
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16. Abstract

A task force has developed FAA Engineering and Development consensus on the integrated aircraft separation assurance system for the National Airspace System. This report details a study of system errors, mid-airs, and near mid-airs, and altitude deviations to define the problem. The system element requirements are defined to provide two levels of backup to the ATC system: a separation violation warning and a final fail safe collision advisory and resolution function.

The current FAA ASA development programs are discussed and the changes are detailed which are required to transition to an integrated ASA system. This report consists of three volumes. Volume I is the Executive Summary with an overview of the work performed by the Task Force. Volume II is the detailed main concept description delineating the required systems and interfaces. Volume III includes appendices, referred to in the main report, which define in detail the specific interfaces and designs required for system integration.

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APPENDIX A

PERFORMANCE OF ATARS AT LONGER RANGES FROM THE DABS SENSOR

D. G. Hamrick

A-1. INTRODUCTION

The performance of Automated Traffic Advisory and Resolution Service (ATARS) is known to degrade noticeably with increased ranges of the aircraft from the Discrete Address Beacon System (DABS) sensor. No previous study has been undertaken to determine the maximum useful service range of ATARS. Most previous studies have investigated ATARS performance at ranges less than 50 nmi. It is important to know what the maximum service range is for several reasons. First, knowledge of the maximum service range can be important in determining how many DABS/ATARS sensors to procure, and in deciding where to place them. Second, during early implementation some sensors will be isolated without neighboring sensors. These sensors must terminate ATARS service at the maximum service range, rather than at a boundary which separates their own service area from that of another sensor. Hence, an in-depth study has been made to determine what the maximum service range is, what modifications and/or additions will improve performance at ranges greater than 50 nmi, and of these, which one(s) are preferred.

The approach used in this study was the following. A Monte Carlo simulation was used to evaluate the performance of the current ATARS algorithm. Encounters involving aircraft with several different speeds were simulated at various ranges from 30 nmi to 100 nmi. Encounters were created which would show both the resolution failure and the false alarm performance of ATARS. The results of these simulations were then evaluated.

It was found that ATARS was able to provide adequate protection for encounters involving high performance aircraft at all ranges out to 100 nmi. ATARS resolves these conflicts using only vertical maneuvers. However, it was observed that the number of false alarms increased significantly with range for these encounters. For encounters involving low performance aircraft, the resolution performance deteriorated noticeably with range. ATARS resolves these encounters with horizontal

maneuvers. At long range, a few resolutions resulting from ATARS false alarms caused hazardous near misses, even though the aircraft would have been safe without any resolution maneuvers.

Having identified this area of poor resolution performance in the ATARS logic, the study proceeded to address the following problem "What must be done to reduce the resolution failures (to zero, if possible) while minimizing the consequent increase in false alarms." The encounters which resulted in unsatisfactory resolution were analyzed in detail. A number of factors which seemed to contribute to poor resolution performance were identified. Several approaches were considered for improving the resolution performance. The approaches were of two types - changing existing ATARS parameters, and modifying existing ATARS logic. Each approach to improving performance was incorporated into the simulation and exercised using the same set of encounters involving low performance aircraft as was used to exercise the current ATARS. The various approaches were compared, taking into account all aspects of performance. A single approach was selected and recommended for incorporation into the current ATARS algorithm.

The maximum service range of ATARS is dependent upon the accuracy of the DABS sensor. If the azimuth accuracy provided by DABS were to improve twofold, the maximum service range of ATARS would be doubled. Thus, it is important to verify the DABS sensor accuracy figures used in the simulation. A brief comparison was made between the radar data generated by the simulation and some real world data obtained recently from field tests.

A-2. THE MONTE CARLO SIMULATION

A Monte Carlo simulation was used to evaluate ATARS performance. Many encounters were simulated, using different geometries, surveillance errors, pilot delays, and escape rates. This section describes the Monte Carlo simulation and the encounters that were simulated.

A-2.1 The Eleven Nominal Scenarios

Two types of encounters were simulated--near collision encounters and safe passage encounters. The former were intended to show the ATARS collision prevention performance and were expected to reveal any late detection or improper resolution problems. The safe passage encounters were ones in which the aircraft at closest approach were separated horizontally by approximately 4500 feet. These were intended to show the false alarm performance of ATARS. Eleven different nominal scenarios were simulated. They are shown in Figure A-2-1. Scenarios A through E are the collision scenarios. Scenarios F through K are the safe passage scenarios.

The nominal collision scenarios are true collision trajectories. However, the simulation generates a number of individual encounters from each nominal scenario. In each encounter, the initial positions and velocities are randomly selected by adding small perturbations to the nominal conditions. The result is a number of unique encounters, each of which has nearly a collision geometry.

In the same way, each of the safe passage scenarios (except for Scenario K) has a nominal closest approach of 4500 feet. The simulation applies perturbations to generate a number of individual encounters which have separations at closest approach in the range of 3000 to 6000 feet.

Scenario K is a scenario that was observed during the ATARS flight tests. The two aircraft are

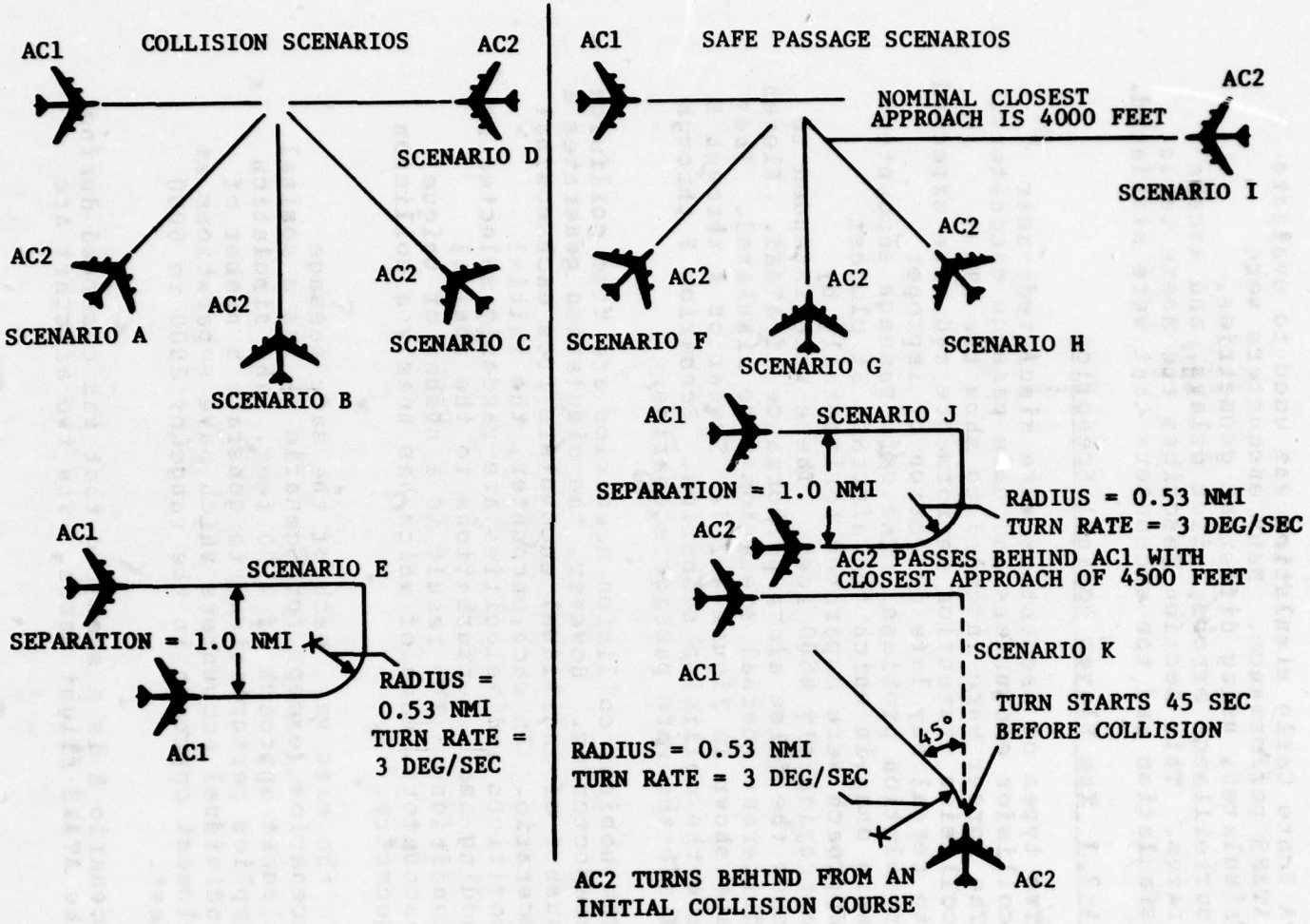


FIGURE A-2-1
THE ELEVEN SIMULATION SCENARIOS

initially on a collision course with their tracks crossing at 90 degrees. Just prior to the time that ATARS selects commands, one pilot begins a turn behind the other, a maneuver which could satisfactorily resolve the encounter. However, due to tracking lag, ATARS is sometimes not aware of the existing turn and it issues a turn advisory in the opposite direction. By the time the pilot can respond to the ATARS advisory, its heading is quite different from that used for the calculation of the advisories. If the pilot does then follow the ATARS advisory, he can be turned back to a near collision course. This scenario is included here because it provides a known challenge to ATARS and could presumably highlight effects caused by reduced surveillance accuracy at longer ranges. Several approaches are presently being investigated in the current ATARS development program to provide relief from this problem.

Both aircraft are initially in level flight in all encounters. The aircraft only depart from level flight if they receive vertical resolution advisories. The true initial altitude separation between the aircraft for each encounter is picked randomly from the range 0 to 200 feet. In all scenarios, both aircraft have the same nominal speed. Three sets of speeds were simulated - 100 knots, 250 knots, and 500 knots. Other scenarios with mixed speeds were not simulated, because there was not sufficient time to do so.

A-2.2 Simulation Parameters

Each nominal encounter was repeated 20 times, with different error samples from the same statistical distribution being used for each repetition. This gave a set of 220 true encounters (11 scenarios X 20 repetitions). Table A-2-1 presents the values used for the significant simulation parameters and assumptions. The dimensions for the three turning encounters, E, J, and K, vary with different speeds. Table A-2-2 gives the necessary values for 100, 250, and 500 knot aircraft.

TABLE A-2-1

SIMULATION PARAMETERS AND ASSUMPTIONS

Radar Azimuth Error Standard Deviation	0.1 deg.
Turn Rate for Escape by 100 Knots Aircraft	6 deg./sec
Climb Rate for Escape by 250 Knots Aircraft	1800 ft./min.
Descent Rate for Escape by 250 Knots Aircraft	1800 ft./min.
Climb Rate for Escape by 500 Knots Aircraft	1000 ft./min.
Descent Rate for Escape by 500 Knots Aircraft	1500 ft./min.
Acceleration for Escape by all Aircraft	7.5 ft./sec.^{2}
Pilot Delay	Uniform Distribution from 5.5 to 8.5 Seconds
Probability of DABS Report on One Scan	0.99
Radar Scan Period	4 Seconds
Both Aircraft Equipped	
Both Aircraft Respond	
ATARS VFR/VFR Logic is Used	

TABLE A-2-2

TURNING ENCOUNTER DIMENSIONS

SPEED	SEPARATION	TURN RATE	RADIUS
100 kts	1.0 nmi	3°/sec	0.53
250 kts	2.0 nmi	2°/sec	1.98
500 kts	7.96 nmi	1°/sec	7.95

A-2.3 Calcomp Plots

Several Calcomp plots are presented throughout this appendix to give a visual image to some of the encounters mentioned in the text. Figure A-2-2 is an example. It is presented here so that the symbolism may be explained. The legend in the upper right corner shows the coding used to represent the various types of ATARS messages. The scale is indicated on the plot by a line of length one nautical mile. Not all plots have the same scale. The true position of an aircraft at each scan is given by the first of three small dots. The true heading is indicated by the alignment of the three dots. The true speed is indicated by the spacing between the three dots. The location of the raw radar report for each aircraft for each scan is represented by a small equilateral triangle. The aircraft are identified by the AC1 or AC2 symbol attached to the first radar report by a leader line.

The current ATARS tracker operates on the raw radar reports and produces tracked positions and velocities for use by the ATARS algorithms. The tracked position is represented by one of the ATARS message symbols. The tracked heading and speed is indicated by the velocity vector emanating from the ATARS message symbol. Finally, every fourth scan is labeled with the scan number and the altitude in hundreds of feet. The scan numbers can be used to locate the positions of the two aircraft at the same time.

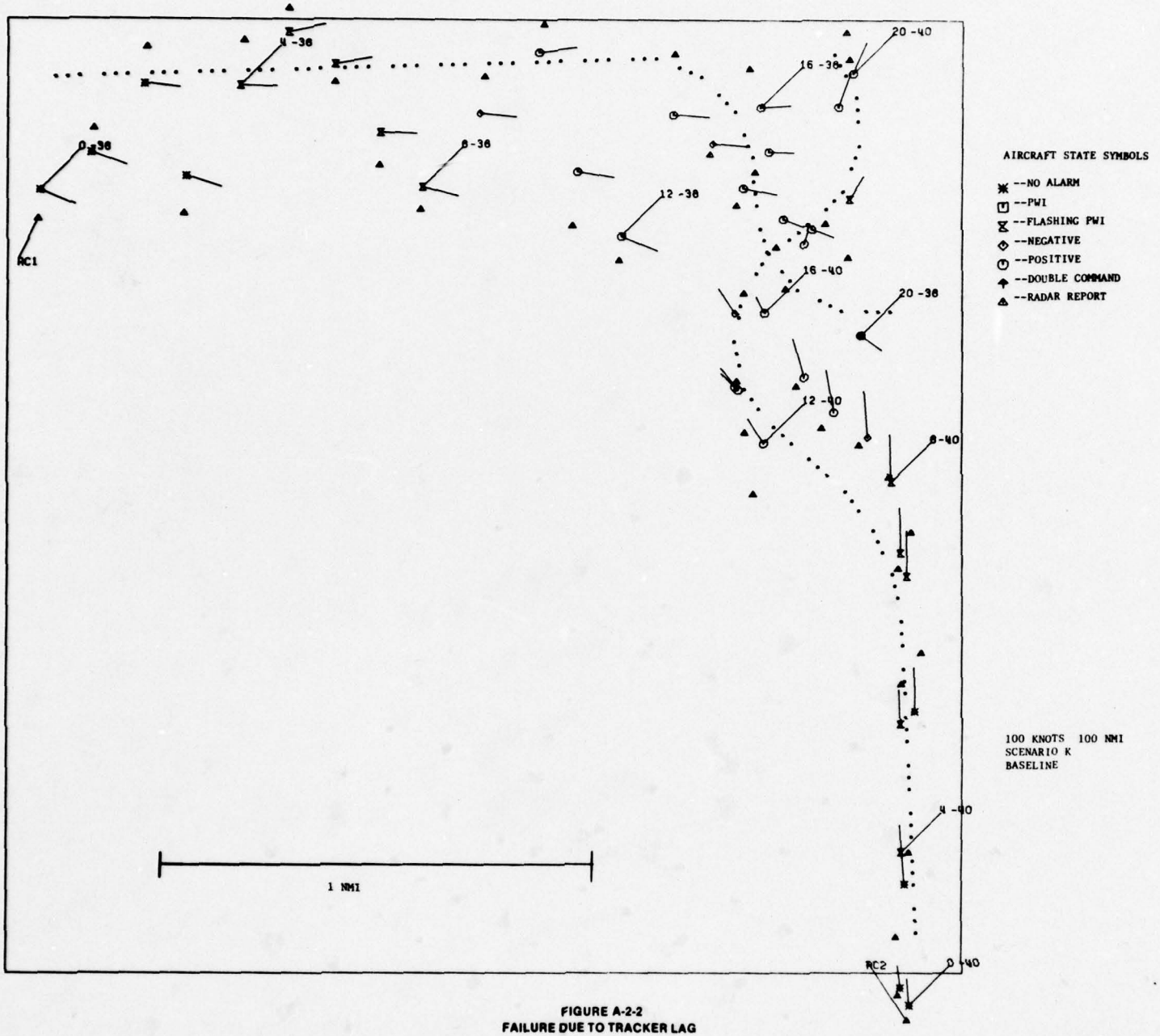


FIGURE A-2-2
FAILURE DUE TO TRACKER LAG

A-3. SUMMARY OF THE CURRENT ATARS LOGIC

Much of the analysis presented in this appendix deals with details of the ATARS algorithms. A familiarity with the fundamental features of ATARS is necessary for an understanding of the discussion that follows. This section provides a summary of the logic and is intended to provide that familiarity. The ATARS algorithms that were simulated in this study are exactly those found in Reference 1.

A-3.1 ATARS Detection Logic

The vertical detection logic is not material to the current study. The horizontal detection logic uses a variable called horizontal tau. The equation for computing horizontal tau is not important at the moment. Horizontal tau (or simply tau) is an approximation to the time remaining before two aircraft will reach their closest horizontal separation, if they continue in linear flight. The horizontal criterion for issuing an ATARS resolution advisory is met on one particular radar scan if tau is less than a threshold, TCMD. TCMD is a threshold which takes different values depending upon the attributes of the encounter (flight rules, ATARS equipage, and speeds of the aircraft). For all encounters simulated in this appendix, both aircraft are assumed to be flying according to Visual Flight Rules (VFR) and both are assumed to be equipped with ATARS. This was done as an expedient. Other types of encounters should be investigated in the future. The value taken by TCMD for these types of encounters in the current ATARS algorithms is given by the parameter, TL2. It has a nominal value of 32 seconds. This parameter is subsequently referred to as the look-ahead time.

An ATARS advisory is normally not issued until the criterion for an advisory has been met on two of three successive scans. However, if tau is less than 25 seconds on the first scan at which the criterion is met, advisories will be issued immediately.

No special logic is involved to determine when to terminate the advisories. ATARS continues to display the advisories for as long as the detection criterion is met. There is a restriction, however, that requires that positive advisories remain displayed for a minimum period of time, once issued. In the current ATARS, this minimum duration is two scans. The ATARS parameter which implements this feature is TSCMD.

A-3.2 ATARS Command Selection Logic

Once the decision to issue resolution advisories has been made, ATARS determines whether they should be issued in the horizontal or vertical dimension. In the case where both aircraft are in level flight, both are VFR, and both are equipped with ATARS, resolution is vertical if the vertical separation based upon tracked altitudes is greater than 370 feet, or if at least one of the aircraft has a tracked speed greater than 150 knots. Resolution is horizontal, otherwise.

When the vertical dimension has been selected for resolution, the advisories are positive (Climb or Descend) if the vertical separation based upon tracked altitudes is greater than 470 feet. The advisories are negative (Don't Climb or Don't Descend), otherwise.

When the horizontal dimension has been selected, the advisories are positive (Turn Left or Turn Right) if the horizontal miss distance is less than 0.5 nmi. (This test is actually performed by comparing the square of horizontal miss distance with the threshold, MDTHSQ.) Horizontal miss distance is the closest separation that two aircraft would have in the future if they were to proceed from their current positions with their current velocities. Negative horizontal advisories would be issued if the horizontal miss distance is greater than 0.5 nmi.

Once the resolution dimension has been selected, all advisories continue to be issued in that same dimension for as long as the detection criterion

continues to be satisfied. Transitions from one dimension to another are not permitted. However, transitions from positive to negative advisories or from negative to positive advisories, within the same dimension are permitted. These take place whenever the horizontal miss distance crosses the 0.5 nmi threshold or the vertical separation crosses the threshold of 470 feet. Transitions are limited only by the requirement that positive advisories remain displayed for a minimum number of scans. Otherwise, they can take effect immediately.

When horizontal resolution advisories (positive or negative) are required, the turn directions are determined by an algorithm which selects one of the following three rules depending upon the geometry of the encounter:

1) Turn each aircraft away from the present position of the other aircraft.

2) Turn each aircraft in the direction that will cause the horizontal miss distance to increase.

3) Turn the aircraft which will pass behind the other so as to cause it to pass further behind. Turn the other aircraft in the opposite direction.

In the case of horizontal negative advisories, the same algorithm that would be used to select horizontal positive advisories is executed. The turn advisories that result are then converted to the appropriate don't turn advisories (i.e., a Turn Left from the algorithm becomes a Don't Turn Right advisory).

An additional feature of the logic is that whenever an advisory transitions from a positive to a negative or vice versa, the advisories will be recomputed. That is, the algorithm to select the directions of turn will be executed again and the new results issued as the new advisories. However, as long as a transition does not occur,

the same advisories will be issued from scan to scan. As a result of this recomputation logic, a pilot could receive a Turn Left advisory followed by a Don't Turn Left advisory. Later in this appendix, such a change is referred to as a change in "sense" of the advisory.

A-4. PERFORMANCE OF CURRENT ATARS BEYOND 50 NAUTICAL MILES

Table A-4-1 presents a summary of results for the simulation of ATARS performance as a function of range. An explanation of the presentation is needed before the results are discussed.

A-4.1 Summary Table Explanation

A collision encounter in which ATARS issued positive advisories was counted as a failure if the two aircraft, while responding to the advisories, reached a point where they simultaneously had less than 200 feet vertical separation and less than 1000 feet horizontal separation. In Table A-4-1, failures are tabulated separately for the four straight scenarios (80 encounters) and the one turning scenario (20 encounters).

A category of failures called "failures caused by false alarms" is also included. A failure in this category comes about when the aircraft response to advisories in a safe passage encounter results in less than 200 feet vertical and 1000 feet horizontal separation. (These encounters would have been safe without resolution advisories. Hence, the failure is considered to be caused by the false alarm.)

An entry in the last category, entitled "false alarms", is generated when a positive advisory is issued for one of the safe passage encounters. The number of false alarms, produced by one modification of ATARS relative to another, is an important factor in evaluating modification to ATARS. The absolute number of false alarms is a function of the nominal safe passage distance simulated. For certain types of encounters (e.g., high speed encounters at high altitude), an advisory that is issued when the minimum horizontal separation is 450 feet may not be considered a false alarm. Hence, the number of false alarms is not intended to be meaningful in an absolute sense.

TABLE A-4-1

PERFORMANCE OF CURRENT ATARS AS A FUNCTION OF RANGE

RANGE	30 NMI	50 NMI	75 NMI	100 NMI
100 KTS				
FAILURES (HORIZONTAL RESOLUTION)				
(100 ENCOUNTERS)				
STRAIGHT (80 ENCOUNTERS)	0	0	0	1
TURNING (20 ENCOUNTERS)	6	7	9	8
FAILURES CAUSED BY FALSE ALARMS	0	1*	1*	2 3*
FALSE ALARMS (110 ENCOUNTERS)	33	46	62	77
AVERAGE DURATION OF TURN ADVISORIES (SCANS)	5.15	6.14	6.10	5.75
250 KTS				
FAILURES (VERTICAL RESOLUTION)				
(100 ENCOUNTERS)				
STRAIGHT (80 ENCOUNTERS)		0		0
TURNING (20 ENCOUNTERS)		5		4
FAILURES CAUSED BY FALSE ALARMS		0		0
FALSE ALARMS (110 ENCOUNTERS)		50		79
500 KTS				
FAILURES (VERTICAL RESOLUTION)				
(100 ENCOUNTERS)				0
STRAIGHT (80 ENCOUNTERS)				
TURNING (20 ENCOUNTERS)				3
FAILURES CAUSED BY FALSE ALARMS				0
FALSE ALARMS (110 ENCOUNTERS)				73

* CAUSED BY SCENARIO K

For the encounters with two 100 knot aircraft, ATARS uses horizontal resolution maneuvers. In this case, the degradation of surveillance accuracy with range could be expected to have an impact on the duration of resolution advisories. The average duration of the turn advisories is shown in Table A-4-1 for the 100 knots simulations.

A-4.2 Results of the Simulation

Table A-4-1 shows that the most significant effect of degraded surveillance at longer ranges is an increase in the number of false alarms. This effect is expected and is inevitable. There is nothing that can be done about the increase in false alarms at longer ranges without compromising safety. Thus, the thrust of this study has been to improve late detection performance while minimizing the asscciated increase in false alarms.

There is little impact of degraded surveillance at longer ranges on late detection. The most severe impact of operating at longer ranges occurs with the 100 knot aircraft which receive horizontal advisories. For the faster aircraft, no significant safety degradation is noted. Most of the caused failures, which occur in the 100 knot simulations, come from scenario K; but two of them come from other scenarios in the simulations at 100 nautical miles. It is noted that no caused failures occur when the resolution is with vertical maneuvers.

The failures shown in the turning cases do not necessarily represent failures of the ATARS system. ATARS Proximity Warning Indicator (PWI) advisories are intended to prevent turns of the sort used in these simulations. However, turning encounters such as this could still occur in unusual situations (perhaps because the pilot of the turning aircraft has visually identified the wrong threat aircraft). Table A-4-1 shows that failures occur in turning encounters even at 30 nmi. Improving ATARS performance in turning

encounters (at all ranges) is an important task that should receive priority in the future development of ATABS.

For the 100 knot simulations, the average duration of the turn advisories is shown. No significant effect is shown as a function of range.

A-5. APPROACHES TO IMPROVING PERFORMANCE AT LONGER RANGES

Two types of modifications to the ATARS logic were considered to improve the resolution failure performance for 100 knot encounters. These were changes to ATARS parameters and changes to the ATARS logic.

A-5.1 ATARS Parameter Changes

The first and simplest modifications to the current ATARS were made to the ATARS parameters. The first approach to improvement was to increase the protection volume parameters. It seemed logical that larger protection volumes would be required to account for the larger surveillance uncertainty at greater ranges. The miss distance threshold, look-ahead time, and minimum duration of positive commands were all increased in several different combinations.

A-5.1.1 Miss Distance Threshold (MD)

The current ATARS uses a horizontal miss distance threshold, MD, of 0.5 nmi. (The actual logic uses the square of this threshold, MDTHSQ.) That is, if ATARS, based on its tracked data, observes a horizontal miss distance less than 0.5 nmi, a positive advisory will be called for. Increasing the miss distance threshold would increase the horizontal protection volume which should provide increased protection in turning encounters.

In reviewing the details of the failure encounters from the simulations with the current ATARS, it was noticed that there were many transitions of advisories (negative-to-positive and positive-to-negative transitions) for the 100 knot simulation at 100 nautical miles. In several cases this led to reversals in the "sense" of the advisories. Thus, the miss distance threshold was increased in an attempt to reduce the number of undesirable transitions, due only to noise.

Table A-5-1 shows the effect of setting the miss

TABLE A-5-1

ATARS PERFORMANCE AT 100 NAUTICAL MILES 100 KNOTS

ATARS PARAMETERS	MD= ½ NMI TL2=32 SEC TSCMD= 7 SEC	MD= ½ NMI TL2=32 SEC TSCMD=15 SEC	MD= ½ NMI TL2=40 SEC TSCMD= 7 SEC	MD= 1 NMI TL2=32 SEC TSCMD= 7 SEC	MD= 1 NMI TL2=40 SEC TSCMD= 7 SEC
FAILURES (OUT OF 100 TOTAL)					
STRAIGHT	1	1	0	0	0
TURNING	8	8	6	8	5
FAILURES CAUSED BY FALSE ALARMS					
STRAIGHT	2	1	0	2	0
TURNING	3*	1*	1*	2*	1
FALSE ALARMS (OUT OF 120 TOTAL)	76	76	85	114	118

* CAUSED BY SCENARIO K

distance threshold to 1 nmi. Column 1 presents results with the current ATARS parameters. Column 4 shows the results with MD = 1 nmi. The number of failures was slightly reduced; however, there was an increase in the number of false alarms. This effect would be expected since the horizontal separation at closest approach for these encounters ranged from 3000 to 6000 feet. As will be shown later, this change proved to be one of the least effective overall.

A-5.1.2 Look-Ahead Time (TL2)

The look-ahead time determines how far in advance of closest approach ATARS issues its advisories. When a large look-ahead time is used, a positive advisory might be generated, even though the aircraft might turn in the near future and no longer be in danger of a collision. Therefore, the current look-ahead time is set to a relatively short 32 seconds. It was felt that increasing this to 40 seconds would allow extra time for the resolution to overcome the effects of a poor initial choice of advisories. Increasing this threshold will also provide additional escape time in cases where the surveillance errors had previously provided insufficient time for resolution. The results with this change are summarized in Table A-5-1, Column 3. This change had a significant effect on reducing the number of failures. The reduction in the number of caused failures is quite significant. Except for the one caused failure from scenario K, the resolution performance is as good as that at 30 nmi.

Because a large improvement in resolution performance was noticed, Table A-5-2 was included to permit a detailed comparison between the use of a 40 second look-ahead time and the current threshold value. The columns marked inner, middle and outer show the number of encounters that had a separation at closest approach of less than 1000 feet horizontal, 200 feet vertical; 2000 feet horizontal, and 350 feet vertical; 3000 feet horizontal, and 500 feet vertical; respectively. An encounter in the inner box would not count in

TABLE A-5-2

DETAILED COMPARISON OF RESOLUTION PERFORMANCE BETWEEN
THE CURRENT AND INCREASED LOOK-AHEAD TIMES

		CURRENT LOOK-AHEAD TIME (32 SECONDS)			INCREASED LOOK-AHEAD TIME (40 SECONDS)		
	SCENARIO	INNER	MIDDLE	OUTER	INNER	MIDDLE	OUTER
COLLISION SCENARIOS	A	0	0	5	0	0	2
	B	0	4	4	0	0	0
	C	0	2	6	0	1	0
	D	1	2	3	0	1	0
	E	8	7	4	6	6	7
SAFE PASSAGE SCENARIOS	F	0	0	0	0	0	0
	G	1	0	0	0	0	0
	H	0	0	0	0	0	0
	I	1	0	1	0	1	2
	J	0	0	0	0	0	1
	K	3	2	0	1	0	0
	TOTALS	14	17	23	7	9	12

INNER BOX: SEPARATION LESS THAN 200 FEET VERTICAL AND 1000 FEET HORIZONTAL

MIDDLE BOX: SEPARATION LESS THAN 350 FEET VERTICAL AND 2000 FEET HORIZONTAL BUT NOT IN INNER BOX

OUTER BOX: SEPARATION LESS THAN 500 FEET VERTICAL AND 3000 FEET HORIZONTAL BUT NOT IN INNER OR MIDDLE BOX

the middle box, etc. A decrease in the number of aircraft pairs falling into the outer two boxes is shown in the case of the increased look-ahead time. This means that more of the encounters were resolved with horizontal separations in excess of 3000 feet. While the longer look-ahead time was useful in avoiding some previous failures, it provides very conservative resolution for many other encounters. This conservative resolution is an undesirable attribute for VFR flight and will tend to amplify the differences between the perception of threat by ATARS and by the pilots. Results of ATARS flight tests (see Reference 2), in which subject pilots were provided a traffic advisory service only and were permitted to provide their own separation, showed that one-third of the subject pilots were willing to accept minimum separations of less than 200 feet vertical and 2000 feet horizontal.

A-5.1.3 Minimum Duration of Positive Advisories (TSCMD)

The last ATARS parameter modified was the minimum duration of positive advisories, TSCMD. In the current ATARS logic, this parameter is set to seven seconds. This causes a positive advisory to be displayed for a minimum of two scans, thereby avoiding rapid transitions from positive to negative advisories due to noise. As stated before, a number of transitions were noted. It was thought that requiring the same positive advisories to remain displayed for a longer period would reduce the liklihood of positive-negative transitions and the resultant recomputation of commands. This recomputation sometimes leads to a reversal of the "sense" of advisory and to ineffective resolution. A new value of 15 seconds was tried for TSCMD. This requires that positive advisories remain displayed for four scans without change.

There was no impact shown by this change on the normal failures, but some improvement in caused failures resulted, as can be seen in Table A-5-1, Column 2.

A-5.1.4 Combined Changes in Miss Distance Threshold and Look-Ahead Time

Increases in the miss distance threshold and look-ahead time were applied simultaneously in an effort to eliminate the one caused failure that remained when the look-ahead time alone was increased. Results are shown in Table A-5-1, Column 5. The caused failure occurring in scenario K was eliminated but another caused failure was introduced in scenario J. This approach was not considered further.

A-5.2 ATARS Logic Modifications

The second major approach to improving resolution performance at long ranges was to modify the existing ATARS logic. This section discusses the effect of the modifications that were studied.

A-5.2.1 Exhaustive Search Algorithm for Advisory Selection

Currently, ATARS utilizes a set of three rules to determine the best horizontal advisories for a given situation. It was postulated that there might exist a better choice of turn direction in some cases. Hence, the current logic was replaced by an exhaustive search algorithm which looks at all possible horizontal turn combinations for two aircraft. Because there are only nine possible combinations, it is feasible to compute the expected separation that would result from each one.

The exhaustive search algorithm assumes that each aircraft, after a nominal delay, turns through a fixed heading change in the indicated direction at a nominal turn rate. It computes the minimum separation that would result if both aircraft were to follow such maneuvers. The process is repeated for all nine combinations of maneuvers. The results are compared to determine the combination that provides the largest minimum separation. For this study of 100 knot aircraft at 100 nautical miles, the turn angle was 60 degrees and the turn

rate was three degrees per second. The exhaustive search approach was taken to see if such a method for determining the turn directions might have less sensitivity to surveillance errors. As Table A-5-3 shows, while some improvement was made in the number of failures caused by false alarms, not all such failures were eliminated. Evidently, the problems with the current ATARS are not caused solely by poor initial choices of maneuvers.

A-5.2.2 The Use of Compatible Negative Advisories

As mentioned earlier, a number of transitions were noted with the current ATARS algorithm. A logic modification that was implemented in an attempt to alleviate this problem was the use of a compatible negative feature in the transition logic. This logic would allow transitions from positive to negative and negative to positive advisories, but would ensure that the "sense" of the command remained the same. For example, a "turn left" and a "don't turn right" would have the same sense while a "turn left" and "don't turn left" would not.

A note should be made here concerning the time delays in the ATARS system. There is inherently a one scan delay between the time the last radar report is received and the time an advisory reaches the aircraft, due to the fact that the radar beam leaves the aircraft before an advisory can be determined. Hence, the system must wait for the next scan to deliver the advisory. There is also a pilot response delay, normally between five and ten seconds. Turning also takes time; at six degrees per second, a 24 degree turn could be made in four seconds, for example. Finally, there is a tracker lag of about three scans. When all these factors are added together it becomes clear that one cannot expect to see any feedback from an advisory in less than roughly six scans. Table A-5-4 summarizes this. The compatible negative routine was implemented in an effort to prevent changing the "sense" of advisories before the ATARS algorithm could be expected to see the results of a positive turn advisory.

TABLE A-5-3

EFFECT OF LOGIC MODIFICATIONS ON ATARS PERFORMANCE AT 100 NAUTICAL MILES AND 100 KNOTS

ALGORITHM	CURRENT RULES	EXHAUSTIVE SEARCH	COMPATIBLE NEGATIVE	TURN TO HEADING	TURN TO HEADING TL2:40 SEC
FAILURES (OUT OF 100 TOTAL)					
STRAIGHT	1	1	0	1	0
TURNING	8	8	9	7	6
FAILURES CAUSED BY FALSE ALARMS					
STRAIGHT	2	1	2	1	0
TURNING	3*	2*	3*	1*	1*
FALSE ALARMS (OUT OF 120)	76	76	76	71	81

* CAUSED BY SCENARIO K

TABLE A-5-4

DELAY IN OBSERVING THE EFFECT OF A POSITIVE ADVISORY

TYPE OF DELAY	SECONDS	SCANS
RADAR CYCLE	4	1
PILOT RESPONSE	5 - 10	1 - 2
ACTUAL TURN	4	1
TRACKER LAG	12	3
TOTAL	25 - 30	6 - 7

The compatible negative logic will issue an advisory that is compatible with (i.e., has the same sense as) an existing one whenever a transition occurs, unless a specified length of time has passed since the last positive advisory was issued. A transition to an advisory of opposite sense is permitted 19 seconds (five scans) after a positive advisory has been issued. This, it was hoped, would reduce the number of failures caused by false alarms; however, no improvement was noticed. (See Table A-5-3.)

A-5.2.3 Turn-to-Heading Algorithm

Another approach to improving resolution performance was the use of a turn-to-heading routine. A turn-to-heading advisory would have the form "Turn Left Heading 310". This approach was tried because reversing the sense of advisories and turning advisories on and off appeared to be problems with the current ATARS logic. Also it was hoped that this approach would show less sensitivity to surveillance errors.

The logic is basically as follows. The exhaustive search algorithm described in Section A-5.2.1 is used to predict what combination of turns will achieve maximum separation. When the detection logic determines that an advisory should be issued, a test is made to see if a turn-to-heading advisory has already been issued. If one has, the logic shuts the advisory off after five scans. However, if a turn-to-heading has not been issued, the logic now issues it.

The turn-to-heading logic is actually in two parts; one for horizontal maneuvers and one for vertical maneuvers. For the horizontal case, the current tracked heading is determined from the x and y velocity components. If the exhaustive search routine determined that a Turn Left advisory was required for one of the aircraft, the turn-to-heading logic would add a specified angle to the current heading (always keeping it in the range between 0 and 360 degrees) to obtain the final desired heading. This angle is the same one

used in the exhaustive search routine, namely 60 degrees. If a Turn Right advisory is required, the specified angle is subtracted from the current heading. The result is issued as an advisory for the pilot to achieve a specific heading. The vertical case is similar; a specified number of feet is added to or subtracted from the current altitude, and this is issued as an advisory to achieve a specific altitude. For testing purposes only, the number of feet was set to 1000. A nominal figure would have to be derived if this routine were to be implemented operationally. Figure A-5-1 presents a flow chart of the turn-to-heading algorithm.

Since a turn-to-heading advisory need only be displayed long enough for the pilot to see it and respond, the display time is arbitrarily set to nineteen seconds (5 scans). This can easily be changed if desired. Once a heading or altitude has been determined and issued, it is never recomputed. This means there can be no transitions or repeated turning on and off of advisories. Therefore, the number of failures that result from reversals and transitions should decrease. Figures A-5-2 and A-5-3 show how an encounter, which resulted in a caused failure with the current ATARS logic and parameters, is satisfactorily resolved with the turn-to-heading routine.

The encounters in Figures A-5-2 and A-5-3 are identical up to scan number 12, at which time advisories are issued by the two logics. The advisories are determined using the tracked position and velocities from scan number 11. The radar failed to provide a radar target report on scan 11 for Aircraft 1 and the ATARS tracker simply extrapolated the track from the conditions at scan 10. Because of the miss, Aircraft 1 was also unable to receive the flashing PWI message which had been generated. Nevertheless, the tracked position and velocity of Aircraft 1 did not have excessive errors. However, Aircraft 2 had substantial errors in tracked position and velocity at scan 11. The true position and

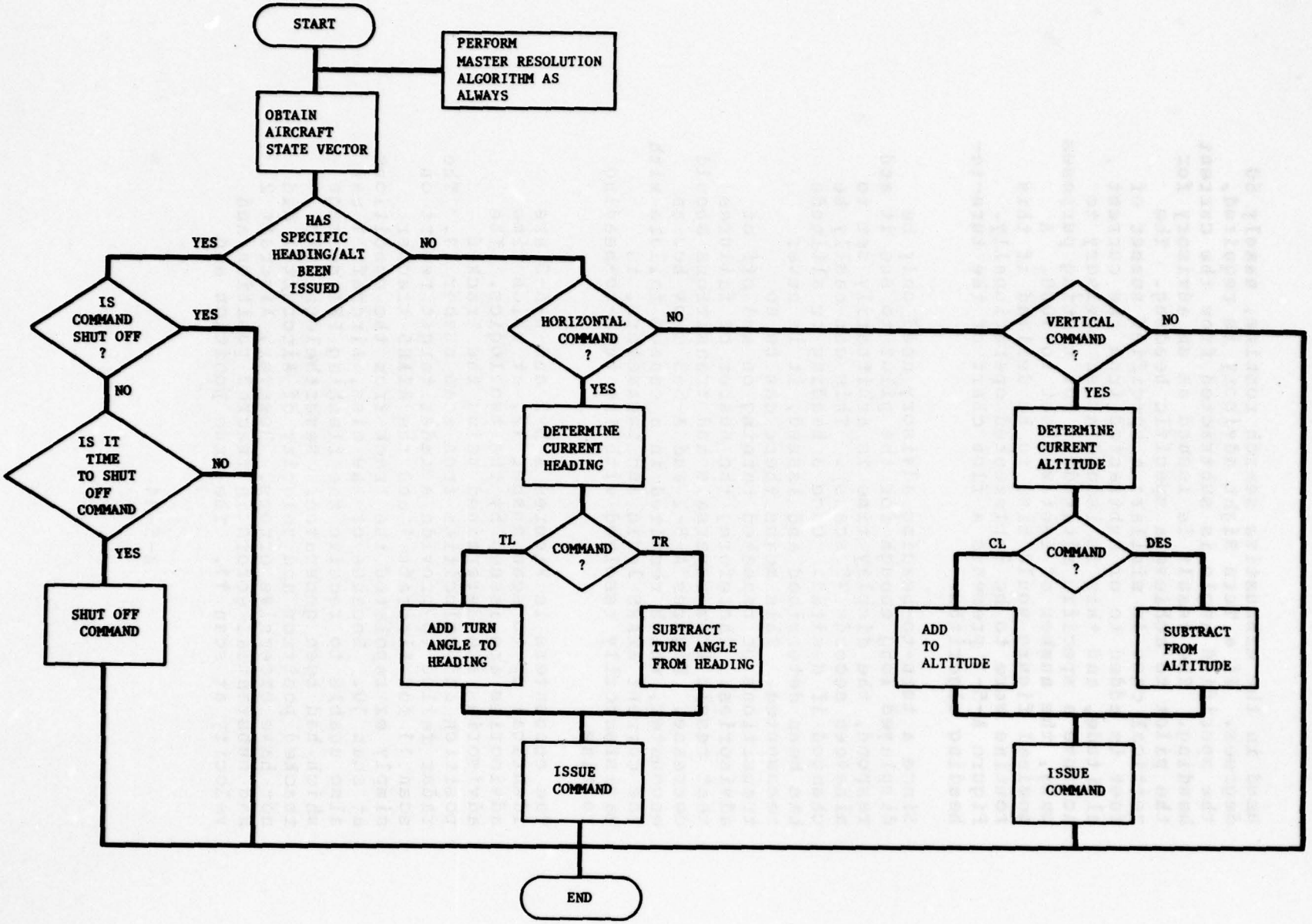


FIGURE A-5-1
TURN-TO-HEADING ALGORITHM

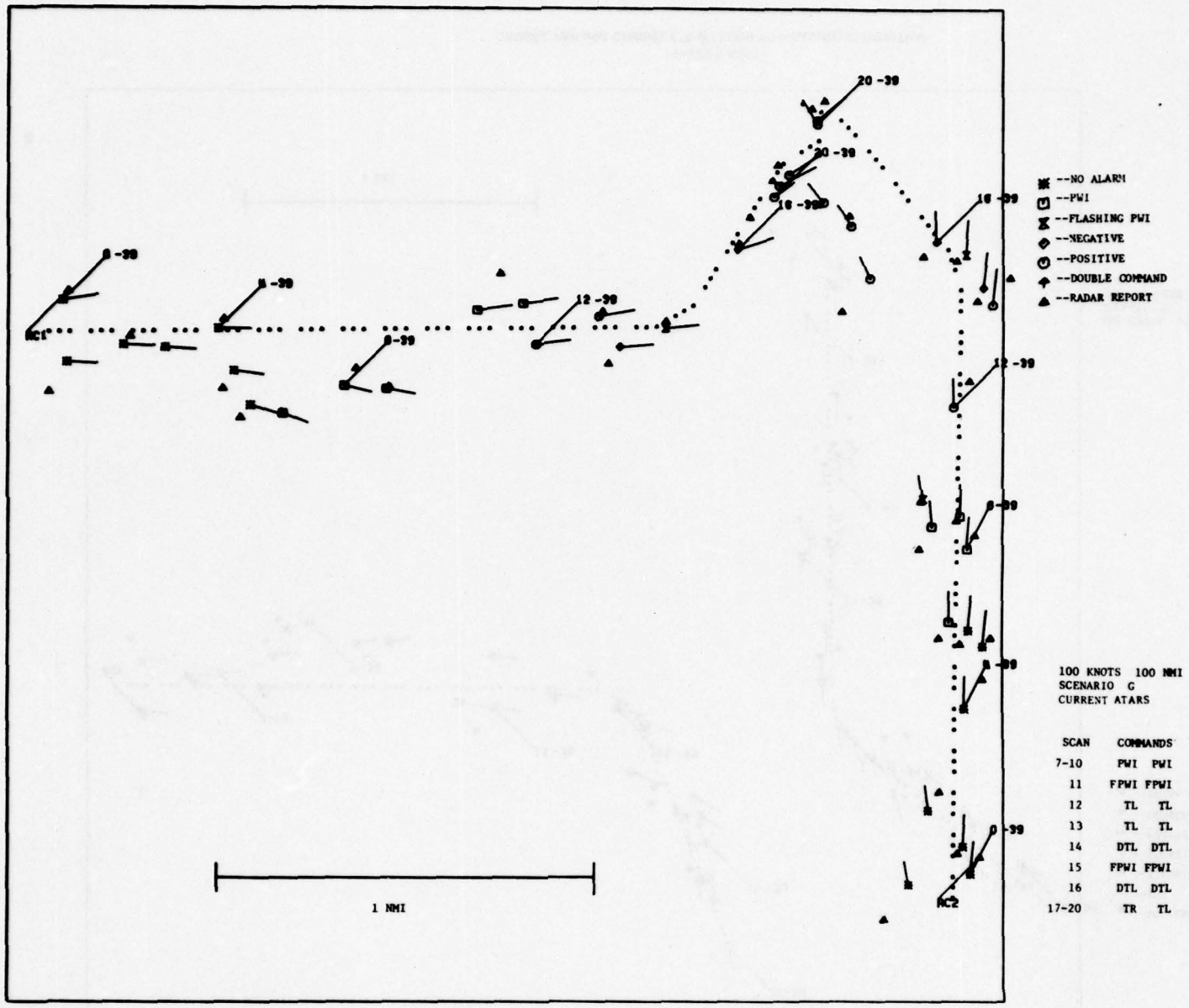


FIGURE A-5-2
FAILURE CAUSED BY POOR COMMAND SELECTION

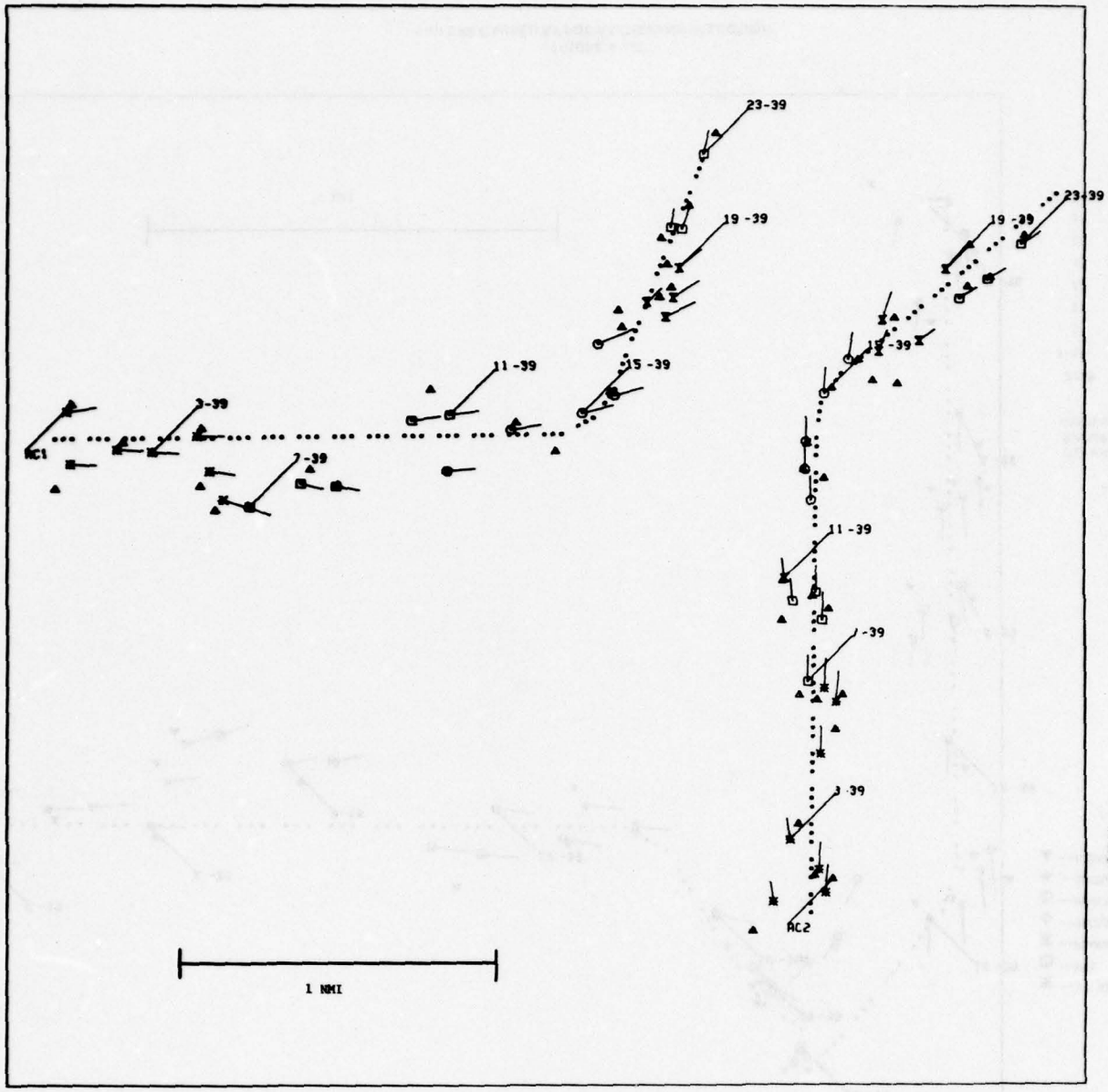


FIGURE A-5-3
CAUSED FAILURE CORRECTED BY TURN-TO-HEADING ALGORITHM

velocity of Aircraft 2 is given by the twelfth set of three dots from the bottom of the figure (the first scan is scan 0). It is clear that the tracked heading of Aircraft 2 is in error to the left and the tracked speed of Aircraft 2 is less than the true speed. As a result, the current ATARS algorithm determined that Turn Left advisories would be correct for both aircraft.

The transition and start-stop characteristics of the current ATARS are evident in Figure A-5-2. The history of ATARS messages for the two aircraft is shown in the figure. The turn-to-heading routine, even though working with the same surveillance errors, selected a 60 degree left turn for Aircraft 1, and a 60 degree right turn for Aircraft 2. This provided very ample separation.

Table A-5-3 summarizes the results of the simulations with the turn-to-heading routine. A slightly greater improvement was found with the turn-to-heading than with the exhaustive search or compatible negative algorithms.

The one failure for the turn-to-heading algorithm in the straight category was caused by scenario B. This failure was noticed with other routines that modified the ATARS logic but was not noticed in the baseline simulations. The reason for this additional failure was not readily apparent. In the programming of the turn-to-heading algorithm, a turn-to-heading advisory is not issued when negative advisories would normally be required. (This was an expedient. An operational turn-to-heading algorithm would have provision for negative advisories.) Consequently, the simulation takes no action when a negative advisory is found to be needed. However, in ignoring the negative advisory, a random number was not generated in the turn-to-heading simulation as was done with the baseline logic. This brought about a different random number sequence from this point to the end of the encounter, which caused different surveillance reports to be generated for the two simulations.

A plot showing the scenario B failure with the turn-to-heading algorithm is presented in Figure A-5-4. On scan 11, the current ATARS algorithm issued a negative advisory. The simulation generated a random pilot delay for response to the negative advisory even though it was not required in this case. The turn-to-heading simulation did not generate this random number. Thus, the sequences of random numbers were different for the two simulations from that point on. The turn-to-heading simulation received a very large surveillance error on scan 12, which the current ATARS logic did not receive. This resulted in different resolution maneuvers and different minimum separations.

In Table A-5-3, the number of false alarms is smaller for the turn-to-heading column than for the current ATARS column. This is also because of different random number sequences which cause the tracked data to indicate a safe passage for the turn-to-heading simulation while indicating a collision threat in the other cases. This is an artifact of the simulation which causes the different algorithms to experience a different set of surveillance reports. No significance should be attached to the differences between numbers of false alarms in this case.

The turn-to-heading algorithm was not as successful as expected. One additional simulation was conducted with the turn-to-heading algorithm using a look-ahead time of 40 seconds, to see if the additional alert time would enable the turn-to-heading algorithm to eliminate all caused failures. The results are shown in the last column of Table A-5-3. Exactly the same results as for the current ATARS logic with a look-ahead time of 40 seconds were obtained. Thus, no unique advantage of the turn-to-heading approach could be shown in these encounters for two 100 knot ATARS-equipped aircraft.

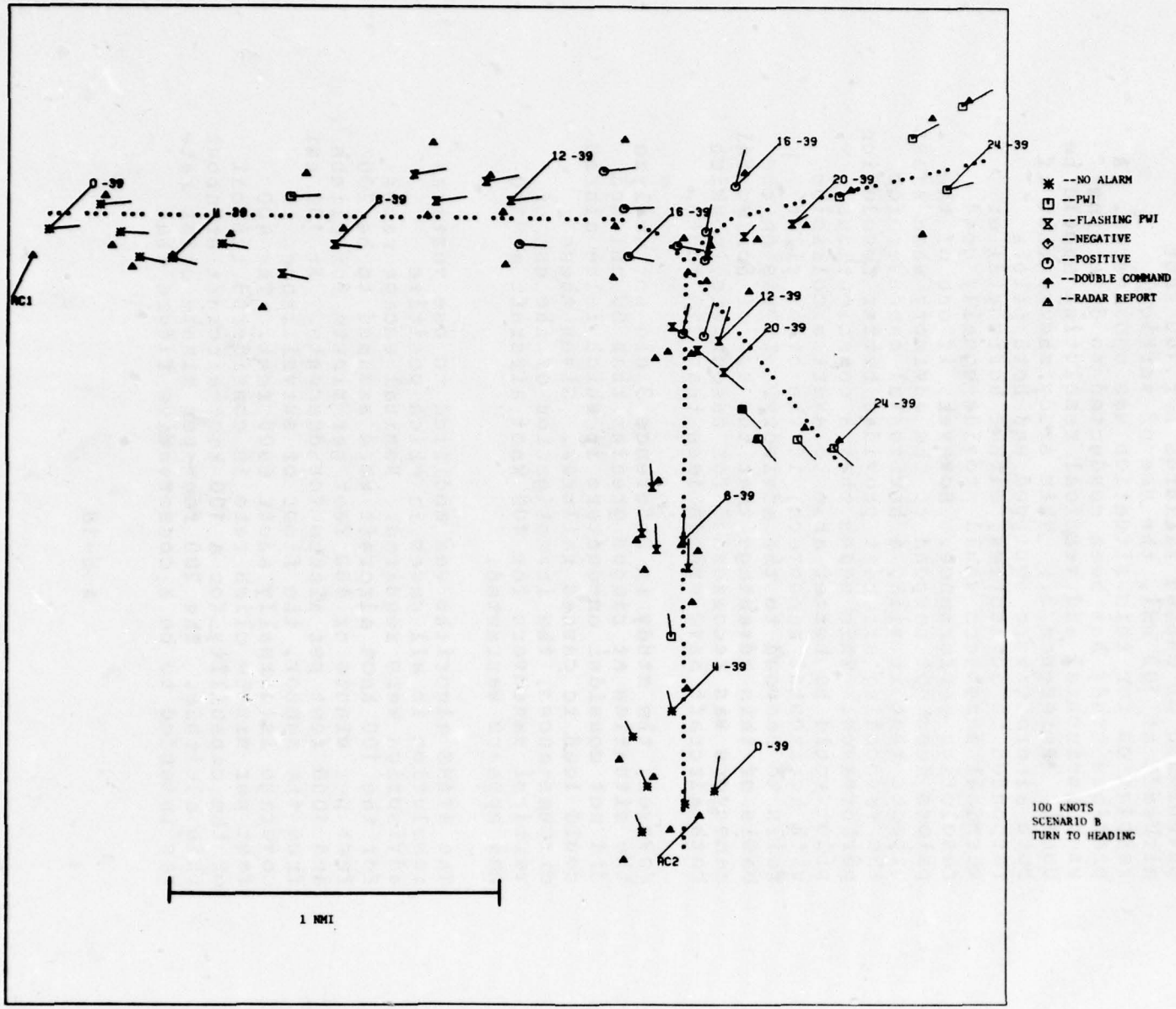


FIGURE A-5-4
RESOLUTION FAILURE OF TURN-TO-HEADING ALGORITHM

A-5.2.4 Use of Vertical Resolution for Low Performance Aircraft

Since none of the horizontal parameter or logic modifications to ATARS was able to eliminate the phenomenon of caused failures for 100 knot aircraft at 100 nmi, the use of vertical resolution for this situation was considered. A previous study has been conducted to determine when horizontal and vertical resolution should be used. (Reference 3.) This study showed that if both aircraft were equipped and both pilots responded to advisories, either horizontal or vertical maneuvers would provide equally good resolution performance. However, if one of the pilots does not respond to the advisory when ATARS expects that it will, a horizontal maneuver for the responding aircraft provides better resolution performance. This means that a conscientious pilot would be better able to avert a collision with horizontal maneuvers, if the other pilot fails to respond to the advisory. It was on the basis of this advantage that the use of horizontal maneuvers was recommended for encounters in which both aircraft have speeds less than 150 knots.

However, the study in Reference 3 did not analyze the situation at ranges greater than 50 nmi and did not consider encounters in which false alarms could lead to caused failures. Given these circumstances, the investigation of the use of vertical maneuvers for 100 knot aircraft at 100 nmi appears warranted.

The ATARS algorithm was modified to use vertical resolution in all cases in which positive advisories were required. Nominal escape rates for the 100 knot aircraft were assumed to be 200 feet per minute or 400 feet per minute for climbs and 1000 feet per minute for descents. At 100 nmi from the sensor, the floor of surveillance coverage is normally about 6000 feet. The 400 feet per minute climb rate is considered typical of the capability for a 100 knot aircraft at about this altitude. The 200 feet per minute climb rate was intended to be a conservative figure that

might apply at higher altitudes. The escape acceleration was 7.5 feet per second squared. The results of the simulations using vertical resolution are presented in Table A-5-5. The results are presented separately for climb rates of 200 feet per minute and 400 feet per minute. Since several failures occurred during straight encounters with a 32 second look-ahead time, simulations with vertical resolution and a 40 second look-ahead time were also conducted. The resolution performance of horizontal maneuvers can be compared with that of vertical maneuvers for both 32 and 40 second look-ahead times in Table A-5-5.

The one caused failure that occurs with vertical advisories and a look-ahead time of 32 seconds actually was not a failure. Had a vertical maneuver been given, no failure would have occurred; however, a negative advisory in the horizontal dimension was the first to be issued, trapping the resolution in that dimension. (The current logic reguires that once the dimension of resolution is determined, all subsequent advisories must be in that same dimension. This feature is being changed in the ongoing ATARS development program. This caused failure would not occur if that change had been implemented.)

The one major advantage of vertical resolution over horizontal, then, is the fact that no failures were caused by false alarms. The number of other failures is comparable to that found in horizontal resolution. Thus, vertical resolution is very promising at 100 nautical miles, especially if an increased look-ahead time is also used.

A-5.3 Recommended Modification

It is recommended that the ATARS logic be modified so that vertical resolution will be used for aircraft of all speeds at ranges greater than 50 nmi, whenever both aircraft in a conflict are equipped with ATARS and both are VFR. The look-ahead time threshold for conflicts of this type

TABLE A-5-5

COMPARISON OF HORIZONTAL AND VERTICAL RESOLUTION AT 100 NAUTICAL MILES FOR 100 KNOT AIRCRAFT

LOOK-AHEAD TIME	32 SECONDS	40 SECONDS	32 SECONDS		40 SECONDS	
RESOLUTION MODE	HORIZONTAL	HORIZONTAL	VERTICAL		VERTICAL	
ESCAPE RATE FOR CLIMB			200 FPM	400 FPM	200 FPM	400 FPM
FAILURES (OUT OF 100 TOTAL)						
STRAIGHT	1	0	3	2	0	0
TURNING	8	6	8	7	7	7
FAILURES CAUSED BY FALSE ALARMS						
STRAIGHT	2	0	0	0	0	0
TURNING	3*	1*	1*	1*	0	0
FALSE ALARMS	76	85	76		85	

* CAUSED BY SCENARIO K

should be increased to 40 seconds at ranges greater than 50 nmi. Further study is required to extend this recommendation to encounters of other types.

A-6. COMPARISON OF SIMULATION AND REAL WORLD RADAR ERRORS

Using a Monte Carlo simulation for evaluating different approaches to improving ATARS performance at long ranges has many advantages. However, the validity of the assumed surveillance errors, pilot delays, etc., must be proved if much credence is to be placed in the results. One method available tc validate surveillance errors is to compare plots of actual radar reports with those of simulated radar reports. This would not be the most desirable verification of the radar error models. A more convincing study would calculate the statistics of the radar errors that were measured in flight. Such a study has been conducted. However, this study (reported in Reference 4) presents only overall statistics. The major concern of the study reported in this appendix has been with the performance of ATARS for 100 knot aircraft at 100 nmi. Most such aircraft visible to a DABS sensor would be at or near the floor of surveillance coverage, which is about 6000 feet above the elevation of the sensor. Thus, the current study should be concerned about radar errors near the floor of coverage. These would be expected to be greater than the errors overall. No statistics on the errors near the coverage floor at a range of 100 nmi were available and resources did not exist to compile such statistics.

Thus, comparable plots of data from the simulation and from the real world have been prepared. This was done using real world data from Clementon, New Jersey, where a transportable DABS sensor had been located temporarily (see Reference 4). The radar was 64 feet above ground on terrain that is fairly flat with no major obstructions. Three aircraft that were observed by this sensor were plotted, one with a circumferential heading (with respect to the radar), and two with a radial heading.

In preparing these plots, a track of interest was selected from the real world data. A simulated aircraft was then developed which had the same

speed, heading, and position with respect to the radar. The simulated aircraft was flown over a trajectory which matched that of the real world track. Radar reports, using an azimuth error of 0.1 degree one-sigma, were simulated. Data from the real world and from the simulation was then plotted to an identical scale. Since the plotting program performs automatic scaling, it was necessary to add one dummy point to the file of radar reports to achieve the same scales. This point appears as an isolated point in one corner of every plot. The coordinates relative to the radar (x-axis towards the East, y-axis towards the North) of the first point on the track are given in parentheses as a means of indicating the aircraft's position and heading relative to the radar. The points plotted are the raw radar reports.

A-6.1 Plots of Circumferential Tracks

Plots of the circumferential tracks are shown in Figures A-6-1 and A-6-2. The aircraft is flying at 130 knots, with a range between 104 and 106 nautical miles. Very little radial error is noticed in the real world plot (Figure A-6-1), which is to be expected. The major part of the error is circumferential causing several relatively large gaps between radar reports. As the simulation plot (Figure A-6-2) shows, the simulated radial error is very conservative. Gaps due to circumferential error can also be found throughout the aircraft's simulated course.

A-6.2 Plots of Radial Tracks

Two sets of radial plots were made, both of the same aircraft. The tracks in Figures A-6-3 and A-6-4 have a range between 92 and 100 nautical miles and altitudes between 5400 and 6100 feet. The aircraft is descending with an approximate heading of 260 degrees. The circumferential error is more apparent in the real world data when the aircraft is flying along a radial. There are enough fairly regular reports, however, to get a good approximation of the aircraft's flight path.

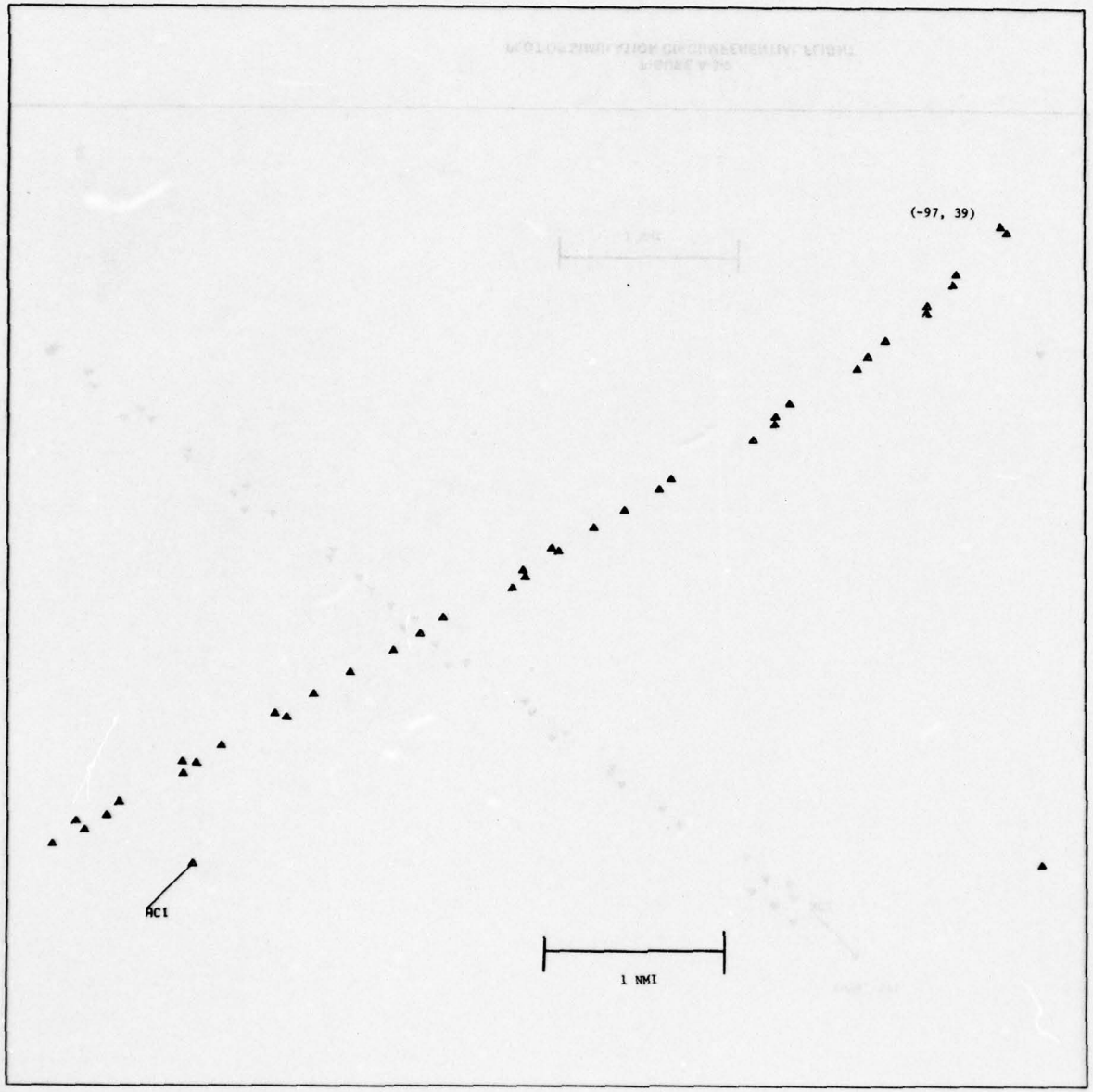
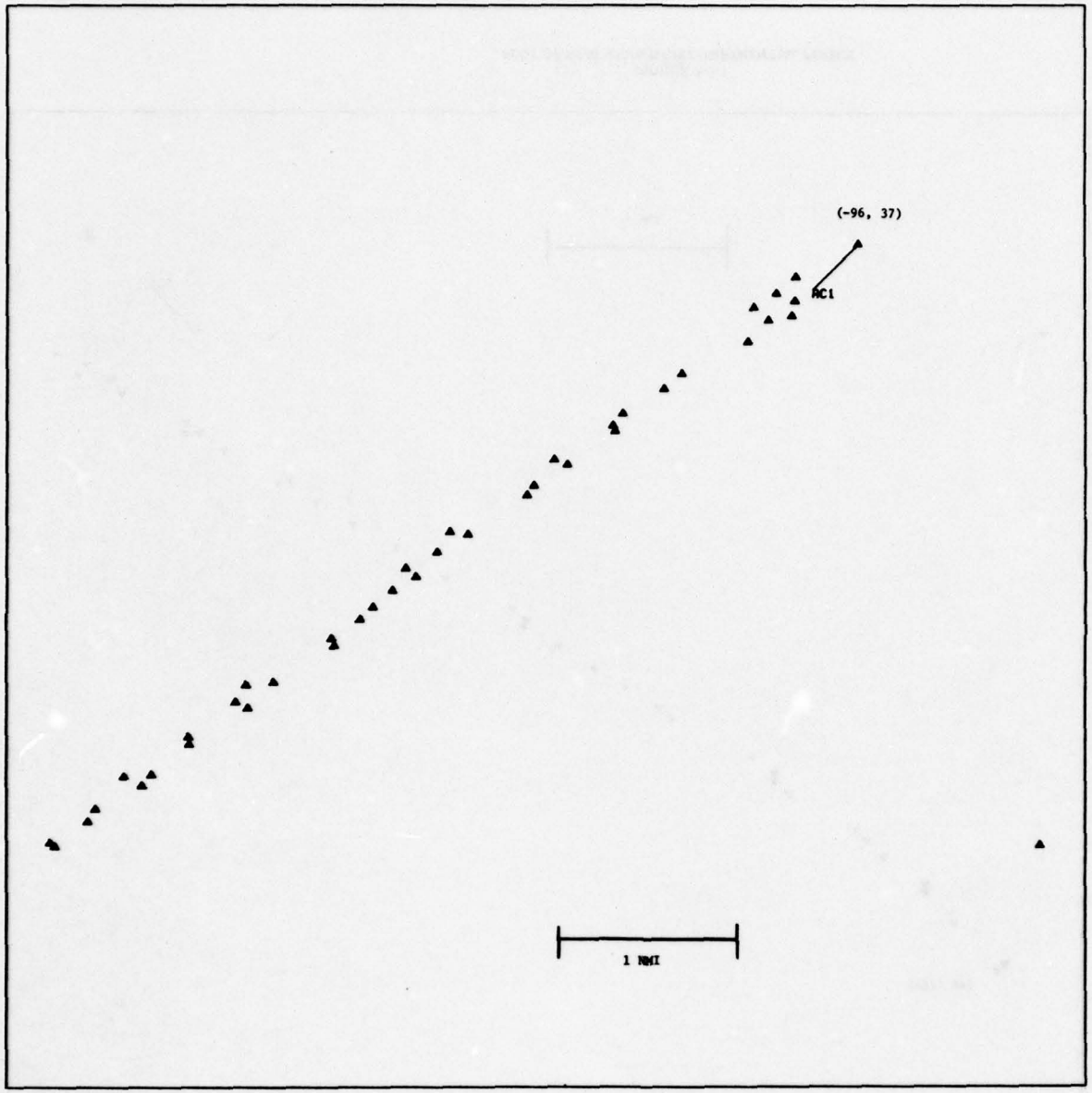


FIGURE A-6-1
PLOT OF REAL WORLD CIRCUMFERENTIAL FLIGHT



▲ - -RADAR REPORT

140 KNOTS
105 - 106 NAUTICAL MILES

FIGURE A-6-2
PLOT OF SIMULATION CIRCUMFERENTIAL FLIGHT

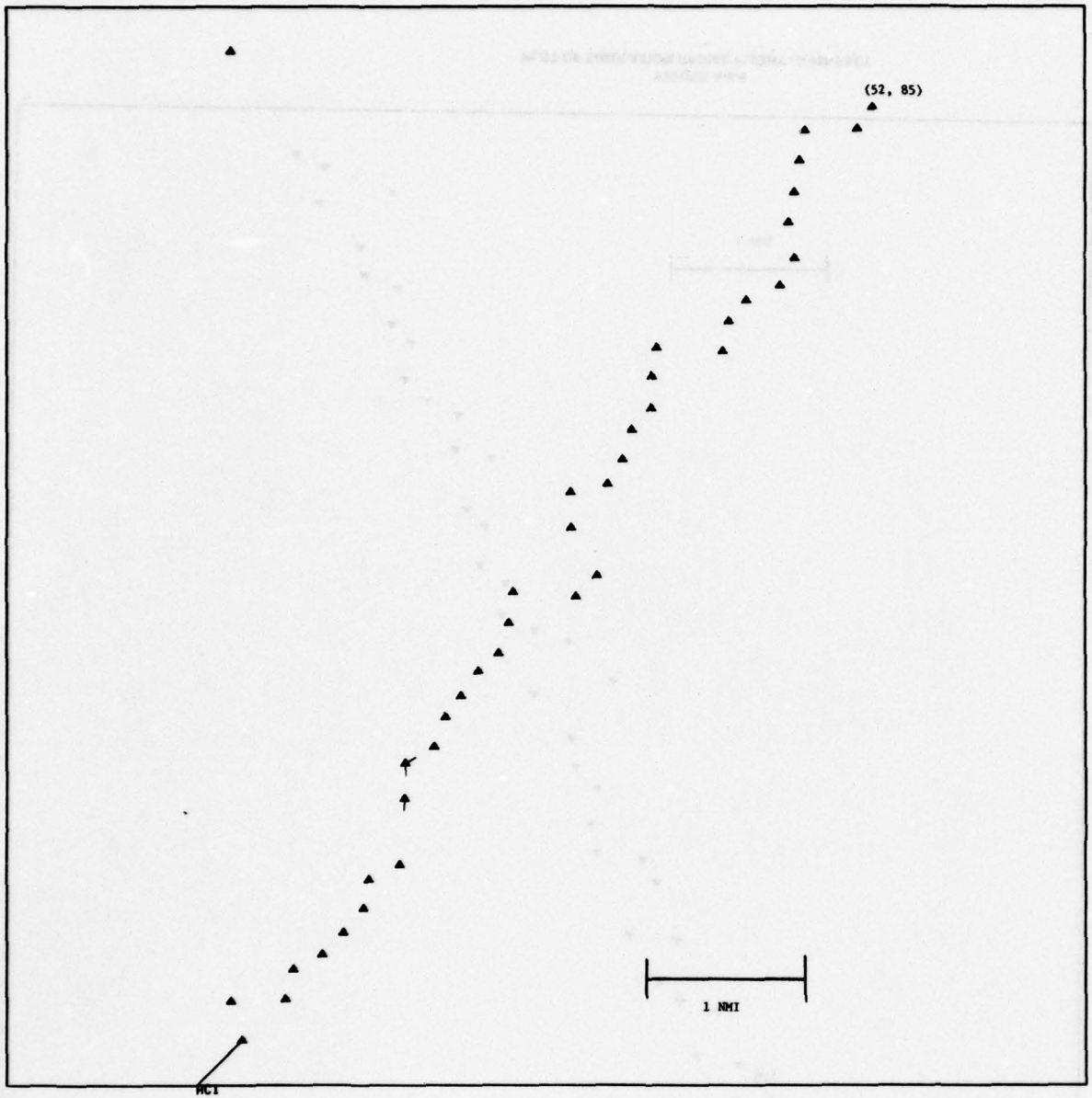


FIGURE A-6-3
PLOT OF REAL WORLD RADIAL FLIGHT - 6,000 FEET

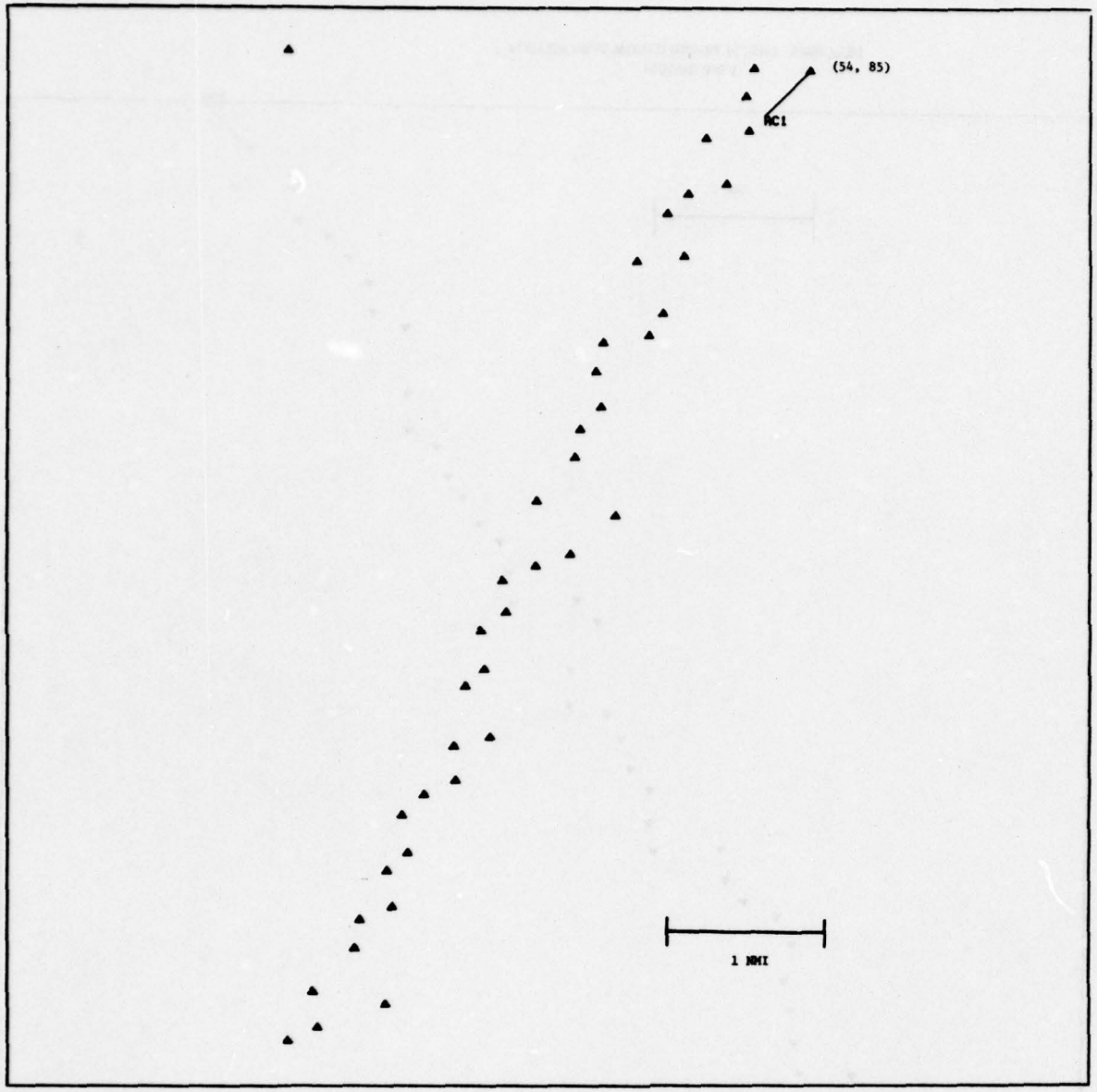


FIGURE A-6-4
PLOT OF SIMULATION RADIAL FLIGHT - 6,000 FEET

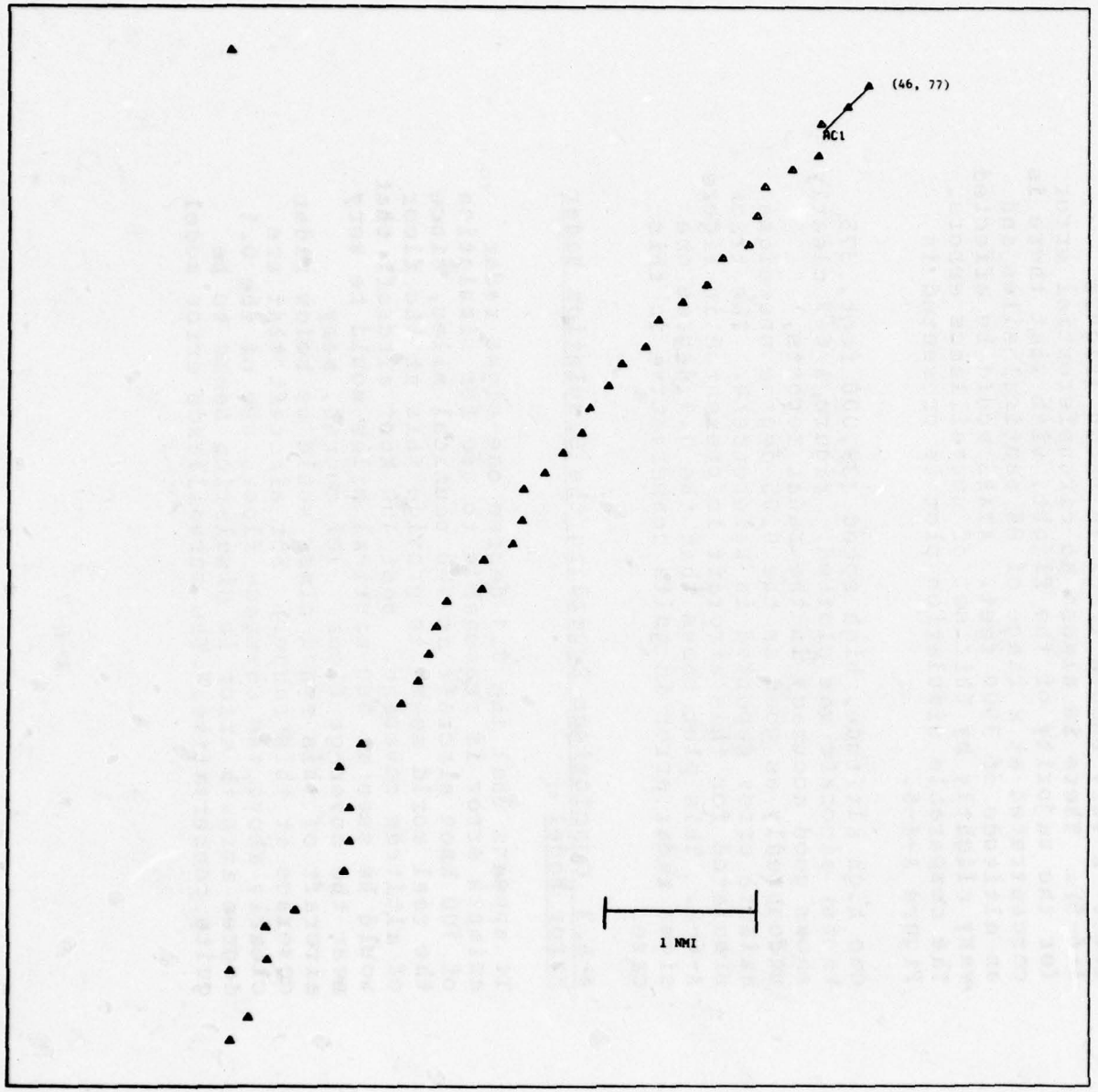
The simulation plot (Figure A-6-4) shows roughly comparable behavior. At a range of 100 nautical miles, the coverage floor is nominally at 6000 feet, which means this aircraft is just at the coverage floor where a larger amount of radar error is normally found.

The second set of simulation and real world plots is from the same aircraft, now at a range of 80 to 90 nautical miles and an altitude of 3900 to 4400 feet. A very smooth track is shown (Figure A-6-5). There is almost no circumferential error for the majority of the flight, with what there is concentrated at a range of 80 nautical miles and an altitude of 3900 feet. ATARS would be affected very slightly by this set of surveillance errors. The comparable simulation plot is presented in Figure A-6-6.

One high altitude, high speed (39,000 feet, 375 knots) aircraft was plotted. Figure A-6-7 clearly shows good accuracy in the radar reports, undoubtedly as good as the 0.05 degree one-sigma azimuth error reported in Reference 4. The track simulated for this aircraft is presented in Figure A-6-8. This plot shows that the 0.1 degree one sigma radar error is quite conservative in this case.

A-6.3 Conclusions Regarding the Simulation Radar Error Model

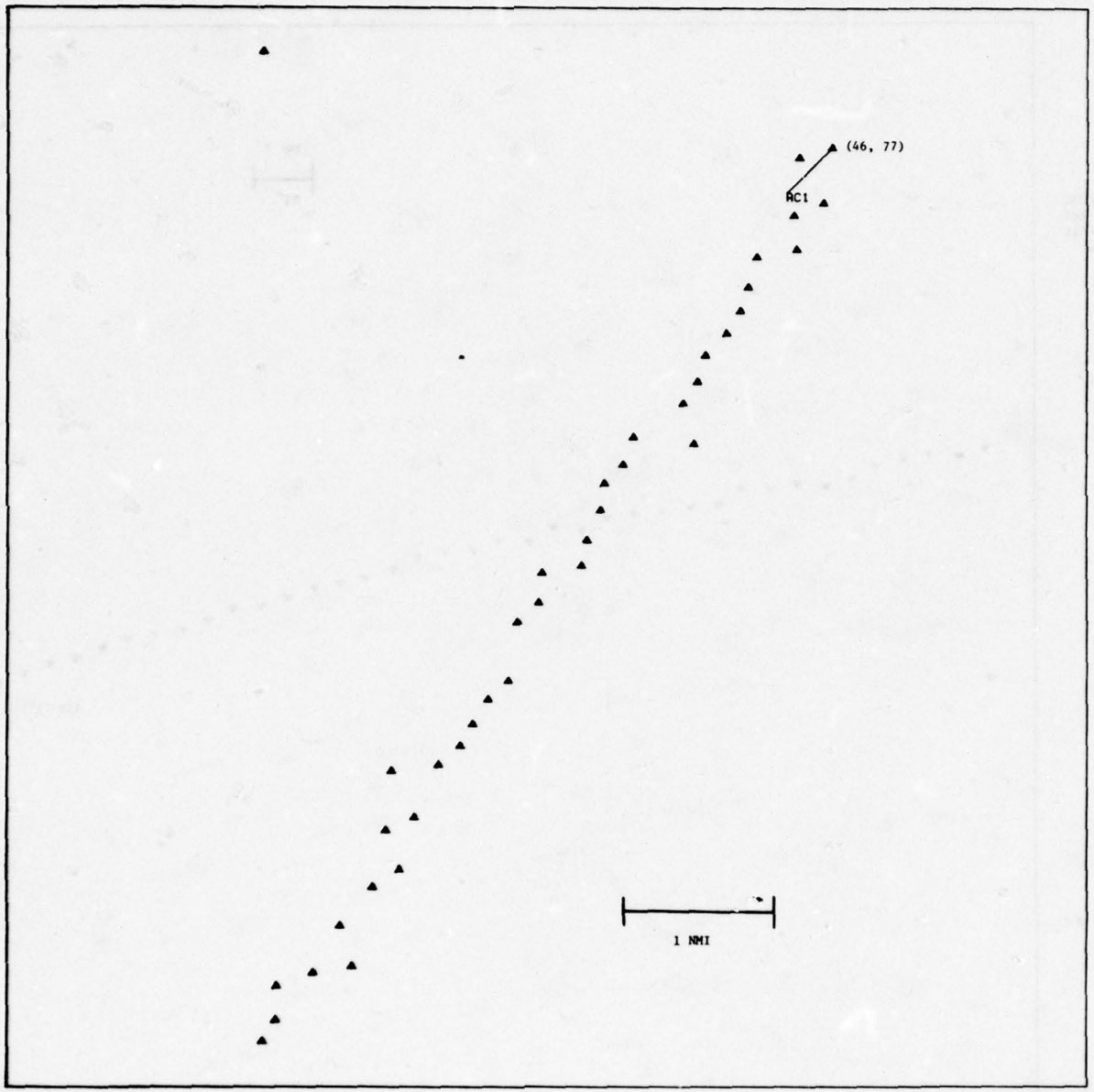
It appears that the 0.1 degree one-sigma radar azimuth error is reasonable to use for simulation of 100 knot aircraft at 100 nautical miles, since the real world seems to provide this at the floor of altitude coverage. Most 100 knot aircraft that would be seen at 100 nautical miles would be very near the coverage floor. (Of course, many aircraft of this speed class would be below radar coverage at this range.) For aircraft that are clearly above the coverage floor, use of the 0.1 degree azimuth error in simulation seems to be quite conservative. The surveillance error model



▲ - -RADAR REPORT

160 KNOTS
80 - 90 NAUTICAL MILES
3900 - 4900 FEET

FIGURE A-6-5
PLOT OF REAL WORLD RADIAL FLIGHT - 4,000 FEET



▲ --RADAR REPORT

160 KNOTS
80 - 90 NAUTICAL MILES
3900 - 4900 ALTITUDE

FIGURE A-6-6
PLOT OF SIMULATION RADIAL FLIGHT - 4,000 FEET

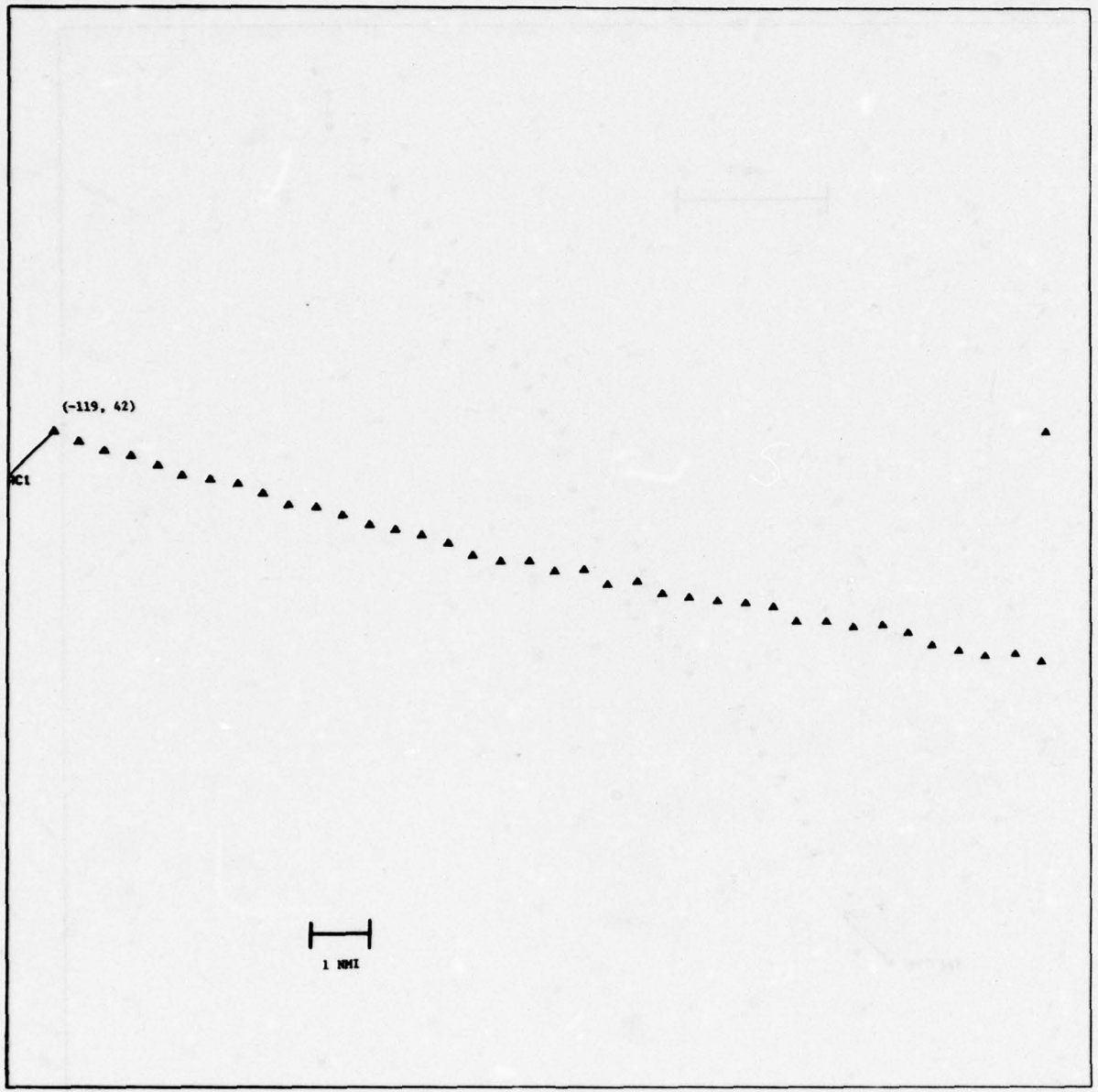
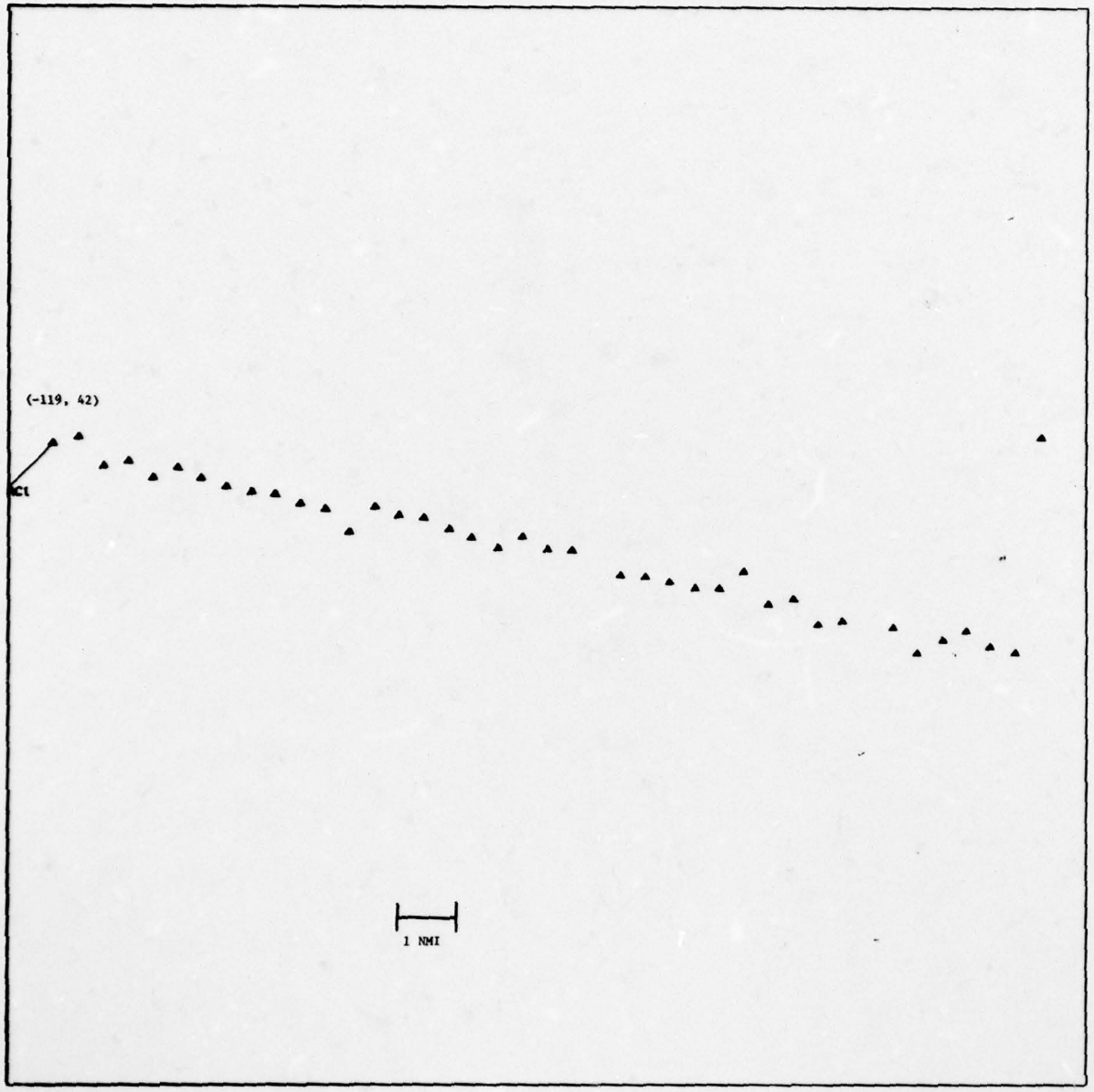


FIGURE A-6-7
PLOT OF REAL WORLD RADIAL FLIGHT - 39,000 FEET



▲ - -RADAR REPORT

375 KNOTS
109-125 NAUTICAL MILES
39,000 FEET

FIGURE A-6-8
PLOT OF SIMULATION RADIAL FLIGHT - 39,000 FEET

of the Monte Carlo simulation provides a conservative representation of the real world situation.

A-7. SUMMARY AND CONCLUSIONS

The resolution performance of the current ATARS for high performance aircrart suffers no degradation when the aircraft are at ranges from the sensor as great as 100 nmi. However, the number of false alarms increases steadily as range increases. The higher false alarm rate at longer ranges is a direct result of the increased surveillance errors. There is no means for preventing the increase in false alarms with range that does not sacrifice safety.

The resolution performance of the current ATARS for low performance aircraft worsens noticeably at longer ranges. Encounters involving low performance aircraft are resolved with horizontal maneuvers. With horizontal maneuvers, an ATARS false alarm can actually cause a hazardous near mid-air situation in an encounter that would have been safe without the ATARS maneuver.

The most effective means of improving ATARS resolution performance with horizontal maneuvers, while minimizing the increase in false alarms, is to increase the look-ahead time from 32 to 40 seconds. However, even this modification did not eliminate all caused failures.

Because the ATARS algorithms can cause resolution failure when false alarms are issued at longer ranges, it is recommended that the ATARS algorithms be modified to use vertical resolution for all encounters beyond 50 nmi, if both aircraft are VFR and are ATARS-equipped. It is also recommended that the look-ahead time for encounters in which both aircraft are equipped, VFR, and have speeds less than 150 knots, be increased from 32 to 40 seconds beyond 50 nmi. When these modifications are used, ATARS provides resolution performance at 100 nmi that is comparable to that at 30 nmi.

The use of a turn-to-heading algorithm for encounters involving two VFR equipped aircraft at longer ranges provides no improvement in

resolution performance relative to the current ATARS algorithm. No conclusion can be drawn from this work about the merit of a turn-to-heading algorithm for encounters in which one aircraft is not equipped with ATABS.

The use of a 0.1 degree one-sigma azimuth error for simulating DABS surveillance errors when aircraft are near the floor of coverage seems to be appropriate, based upon the brief qualitative comparison of simulation and real-world errors conducted here. When aircraft are well above the coverage floor, use of a 0.1 degree one-sigma azimuth error provides a conservative model for radar azimuth errors.

All other aspects of the ATABS logic and a wider variety of geometries should be analyzed before the study of ATABS performance at long range is considered complete. Additional study should consider equipped-unequipped, IFR-VFR, vertically maneuvering and mixed speed encounters.

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APPENDIX B

COMAPRISON OF IMPLEMENTING ATARS AT THE DABS SITE VS. THE ATC FACILITY

D. J. Bryant

B-1. INTRODUCTION

In this appendix the cost tradeoffs between two alternative siting scenarios for Automatic Traffic Advisory and Resolution Service (ATARS) are investigated and both quantitative and qualitative differences of the two systems are addressed.

As originally designed, ATARS is an integral part of the Discrete Address Beacon System (DABS). Its function is to provide automated collision avoidance protection to Instrument Flight Rules, (IFR) and Visual Flight Rules, (VFR) aircraft equipped with DABS transponders and cockpit displays. An engineering model DABS, incorporating the ATARS features, has been delivered to National Aviation Facilities Experimental Center (NAFEC) for testing and evaluation. The specifications for this engineering model have been used as a baseline for making the system comparisons presented in this study. Specifically, the ATARS system located at the DABS site has been assumed to perform as specified in the DABS Engineering Requirement (ER) (see References 1 and 2). No attempt has been made in this document to verify either the reliability or maintainability estimates provided by the DABS contractor, or to forecast the outcome of NAFEC testing.

The second alternative for the location of ATARS involves relocating the collision avoidance hardware and software away from the DABS radar site to the local Air Traffic Control (ATC) facility. For terminal radars the physical separation of these two locations is generally small--under 5 miles. For long range, en route, radars, the distance between the two locations can be much larger, stretching to several hundred miles. In either case, the ATARS that would be implemented at the ATC facility in this alternative has been assumed to meet the requirements of the DABS ER. In this way differences between the alternatives of ATARS located at the DABS site and located at the ATC facility, can be quantized in terms of cost while

maintaining as nearly as possible the same performance.

In general, cost information has been presented on a per site basis using as a baseline, costs associated with the engineering model DABS and ATARS. However, in some instances averaged system costs or estimated costs associated with a production version DABS may represent a more realistic indication of the true cost difference. Where average costs have been used, this has been clearly noted, along with the assumptions necessary to arrive at the cost figures given.

Future refinements in the designs of DABS and/or ATARS that may come out of the NAFEC testing have not been factored into this analysis. Rather, an attempt has made to identify some potential changes in the hardware and software and to report their probable impact on the cost question.

B-2. DEFINITIONS OF THE ALTERNATIVES

The two alternatives described below have been chosen tc be nearly equal in performance, meeting the specifications given in the DABS ER, with both alternatives performing the function of collision avoidance for appropriately equipped IFR and VFR aircraft. Each alternative has both terminal and long range radar components with the terminal installations providing surveillance data to the local ATC facility and the Air Route Surveillance Radars (ARSR's or long range radars) tied into the regional Air Route Traffic Control Center (ARTCC). The terminal radars have a single antenna face rotating at about 12-15 rpm giving a complete scan every 4-4.7 seconds. The long range radars are dual faced, having two antennas operating in the back-to-back mode. These rotate at a much slower rate, about 5-6 rpm. Use of the back-to-back antennas, however, gives a higher effective scan rate, with one complete scan every 5-6 seconds.

As required in the ER, both the site-located-ATARS and the facility-located-ATARS have the capability of communicating with adjacent sites for handoffs, remote surveillance and ATARS multiple uplinks. These sites are asssmed to be tied together for intersite communications via a master network generally modeled after the lower cost Star network presented in Reference 3. In this design, adjacent DABS/ATARS sites communicate over direct lines to the ARTCC. Here, a special switch similar to that proposed for the National Airspace Data In Interchange Network (NADIN) directs messages to the appropriate outgoing line. (This communications architecture is referred to as a Star network.) Costs are kept down by using existing two-way ARTS to National Airspace System (NAS) lines for the DABS/ATARS to NAS links. (NAS is used here as an abbreviation

to mean the NAS En Route Computer system located at an ARTCC.) This is feasible since terminal DABS sites are located within a short distance of the ATC facility that they serve and the cost of upgrading these lines is generally less than the cost of adding new lines. Although most ARTS III sites are currently tied to NAS, projections call for only some of the ARTS II sites to be tied in; if these sites are to be part of the interconnected DABS network, additional lines at full cost would have to be used. In addition to development of the NADIN switch, it is assumed implicitly in the Star network that some hardware or software could be provided at the ARTS end of the ARTS/NAS line to switch messages from NAS to ARTS or DABS. This hardware or software would also handle data in the other direction, multiplexing ARTS and DABS messages addressed to NAS.

It is also assumed that long range radar sites will be a part of the DABS network along with the terminal sites, and that these long range sites, in many cases, will have terminal radars as their nearest neighbors. While these en route radars would continue to provide radar surveillance data to NAS for all aircraft within a large airspace volume, they would provide ATARS service in a smaller volume since absolute azimuth errors increase with distance causing degraded ATARS performance beyond 100 nmi. Under this assumption, en route radars would hand off aircraft to nearby terminal radars for collision avoidance protection while continuing to provide NAS with surveillance on that aircraft. This means that ATARS would generally hand off responsibility from an en route radar to a terminal radar, rather than only to another en route radar.

B-2.1 ATARS at the DABS Site

The engineering model design has been taken as representative of a production model ATARS

of the type to be located at the radar site. In this design, ATARS receives target reports from DABS via global memory with ATARS operating essentially independently of DABS. DABS writes these target reports for ATARS use into a buffer in global memory within 3/32 of a scan after detecting the target. ATARS systematically extracts the reports from this buffer and performs its own tracking. After completion of collision avoidance processing, ATARS returns resolution advisories for aircraft to the DABS sensor by writing these into the uplink buffer located in global memory. DABS reads the advisories from this buffer and uplinks them to the appropriate aircraft when the antenna is pointed in the correct direction. This provides an extremely simple and efficient communications system, with all communication between DABS and ATARS taking place internally through global memory. In addition, the engineering model DABS handles all external communications for the ATARS software, writing incoming messages into appropriate sections of global memory.

Primary external communications originated by ATARS include uplinks to aircraft, controller alerts which are passed to an ATC facility and conflict table exchanges with remote ATARS sensors. Inputs to ATARS include the surveillance reports from the DABS sensor, conflict table exchange messages from remote ATARS sensors and non-surveillance inputs including pilot test requests, acknowledgments and data link requests. Among these, surveillance makes up, by far, the greatest volume of inputs with one report received for each target on each scan.

B-2.2 Surveillance and Communications Overview

Upon receipt of a beacon report, DABS attempts to correlate that report with reports received from the primary radar

digitizer. If successful, DABS prepares a radar-reinforced digital-surveillance report for transmission to ATC. A similar report is also written into global memory for access by ATARS. If the beacon report cannot be successfully correlated, slightly different messages are sent to ATC and written into global memory. ATARS continuously reads the surveillance buffer containing the target reports and begins track correlation. If, in collision avoidance processing, a conflict is detected, ATARS writes aircraft messages into the uplink buffer and writes a controller alert into the controller alert buffer. For conflicts occuring in "seams" between sites, coordination must be provided tc resolve site responsibility and guarantee compatible selection of resolution advisories. This coordination takes place through exchange of conflict tables between remote sensors.

Remote sites also impact the advisory selection process if the local sensor has lost contact with an aircraft under its jurisdiction. In this case, request for data is sent to an adjacent sensor which provides a target report. These reports are sent to ATARS through DABS just as are local surveillance reports. ATARS can also request multiple uplink of advisories from adjacent DABS sensors. Requests for this service are transmitted through the local DABS to an adjacent sensor via the Star network (Figure B-2-1) and the modified NADIN switch mentioned earlier. In the site-located ATARS design, messages from the local ATC facility could be sent to the local DABS where they would be added to the communications line and forwarded to the ARTCC. Here, an appropriate switching function would sort out messages addressed to the NAS en route system from messages addressed to other DABS sites, forwarding ongoing messages to the appropriate site.

Figure B-2-1 shows two possible

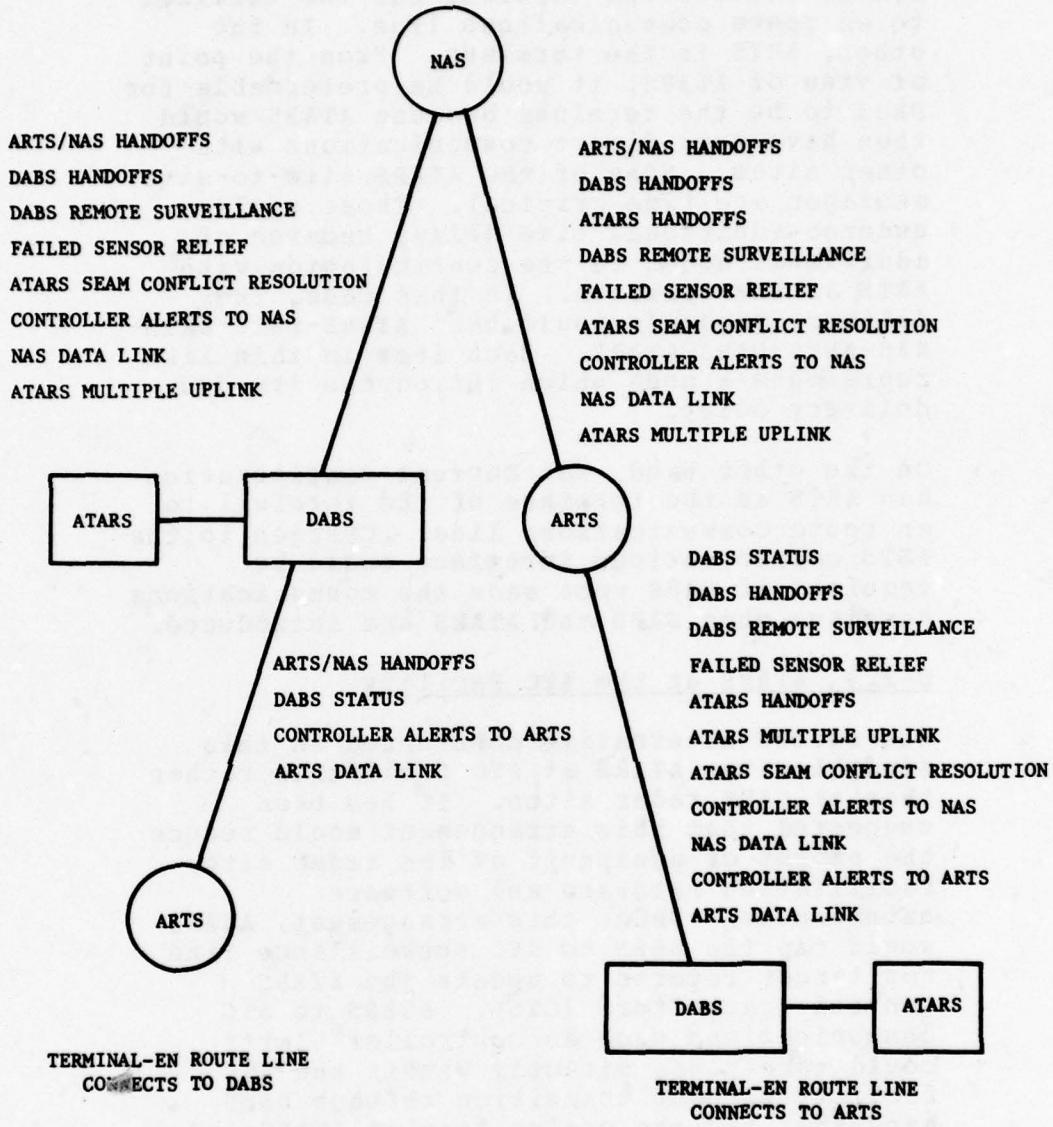


FIGURE B-2-1
STAR NETWORKS FOR TERMINAL TO EN ROUTE COMMUNICATIONS
FOR SITE-LOCATED ATARS

configurations for the Star network when ATARS is at the DABS site. In one, the DABS system becomes the terminus for the terminal to en route communications line. In the other, ARTS is the terminus. From the point of view of ATARS, it would be preferrable for DABS to be the terminus because ATARS would then have more direct communications with other sites. Some of the ATARS site-to-site messages are time critical. These would undergo additional time delays because of additional nodes in the configuration with ARTS as the terminus. In this case, the delivery sequence would be: ATARS-DABS-ARTS-NAS-ARTS-DABS-ATARS. Each item in this list represents a node which introduces its own delivery delay.

On the other hand, the current configuration has ARTS as the terminus of the terminal to en route communications line. Changes to the ARTS communications interface would be required if DABS were made the communications terminus when DABS and ATARS are introduced.

B-2.3 ATARS at the ATC Facility

The second alternative considered in this study locates ATARS at ATC facilities rather than at DABS radar sites. It has been suggested that this arrangement would reduce the amount of equipment at the radar site, facilitating hardware and software maintenance. Under this arrangement, ATARS would tap the DABS to ATC surveillance line for target reports to update the ATARS Central Track Store (CTS). ATARS to ATC communications such as controller alerts could take place directly within the ATC facility without transition through DABS hardware, and the co-location of ATARS and ATC would permit easier access to ATC data such as flight plans and wind maps, if such data were eventually to be used by ATARS. (This data is not used in the current ATARS design.)

Uplinks to conflicting aircraft would be sent to DABS over a two-way communications line linking the facility-located ATARS with DABS. Figure B-2-2 shows the two possible communications configurations when ATARS is located at the ARTS facility. In one case DABS is the terminus of the terminal to en route communications line. In the other ARTS is the terminus. When ATARS is implemented within ARTS, it is preferrable to have ARTS as the terminus to reduce the communications delay for ATARS site-to-site messages.

Reliability of the ATARS function could be maximized by having it reside in its own computer complex co-located with the ATC computers, rather than in the ATC computers. This would facilitate computer-to-computer communications while not degrading the ARTS or NAS equipment. This also provides for standardization, with the system designed for ARTS III also useable at ARTS II installations which do not have the computer capacity or the tracking algorithms required to perform ATARS processing internally. Although ARTS III and NAS installations may have some additional computer capacity available, it would be desirable at these locations to maintain the separation of ATARS and ATC computers so that ATARS would continue to provide collision avoidance protection in the event of failure of the ATC equipment. Such an arrangement would be essential if the reliability of ATARS at ATC facilities is to be as high as for ATARS at DABS sites.

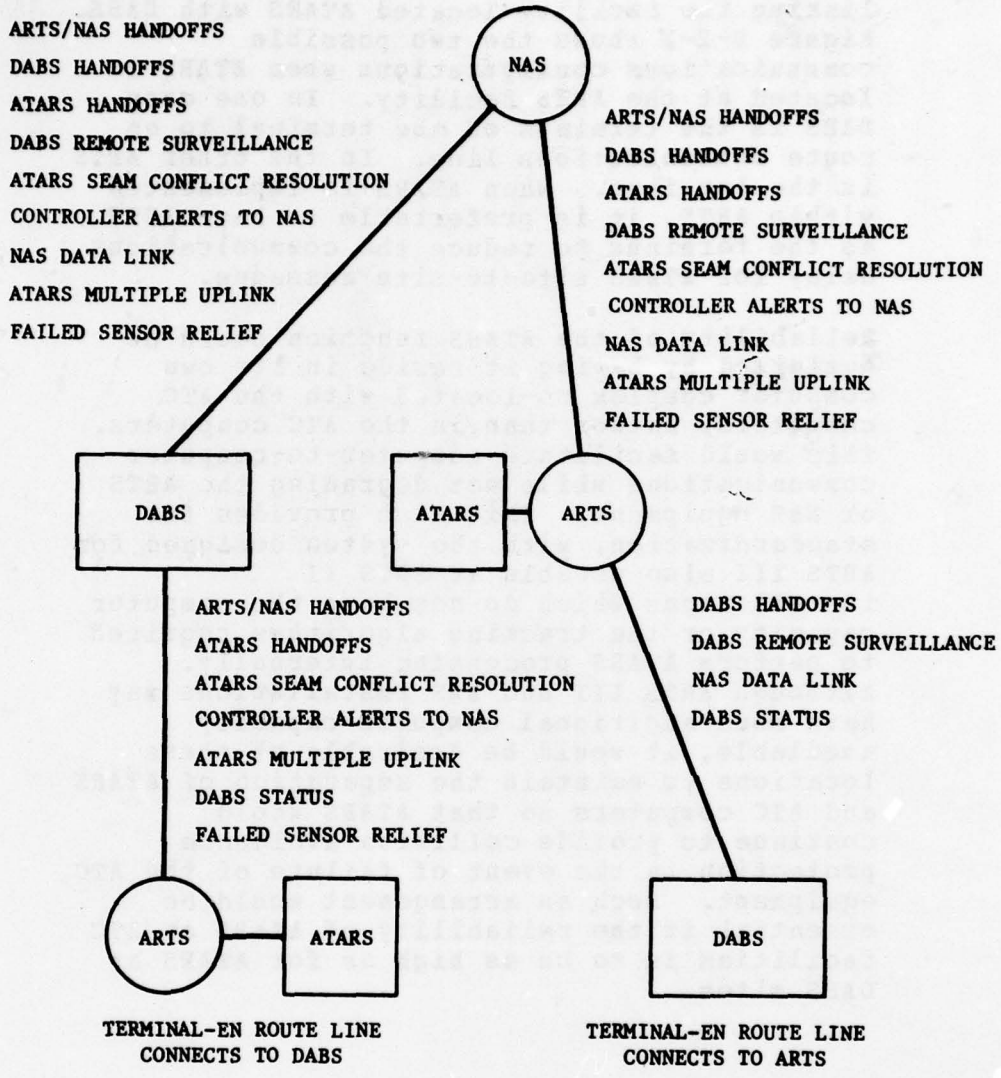


FIGURE B-2-2
STAR NETWORKS FOR TERMINAL TO EN ROUTE COMMUNICATIONS FOR FACILITY LOCATED ATARS

B-3. QUALITATIVE DIFFERENCES AND SIMILARITIES OF THE ALTERNATIVES

Although there are many items affecting the overall cost of the two alternatives, only those that differ from one to the other are examined in this analysis. In this respect, this is not a cost analysis, but a cost difference analysis addressing only items that differ substantially between the alternatives. In this way, it is possible to exclude from consideration future refinements such as a through the transponder, multi-site coordination logic or a new sector oriented approach to ATARS processing (see Appendix G) which would affect both alternatives equally. Excluded also are the costs of design changes to the engineering model system necessary to accomodate ATARS at the ATC facility. This means that the effect of rewriting software in accordance with facility-located ATARS has not been included, but that additional hardware necessary to perform those functions has been included. Thus, the cost differences considered are only the procurement and operations costs. They do not include development costs.

One costly function, the method of multi-site coordination, has been assumed to "wash across" the location question, playing no part in the cost differencing between the two alternatives. As stated earlier, site-to-site communication has been assumed to take place using the Star network of Reference 3 with no cost advantage given to either alternative. Although ATARS at ATC would have to communicate with the remotely located DABS for uplink of ATARS messages, no additional cost is associated with adding the small volume of ATARS to DABS non-surveillance communications to the already existing (assumed under the Star concept) two-way ATC to DABS line. In this study, no detailed design effort has been directed toward establishing the protocol, or the software and hardware requirements for this DABS/ATC interface, as such an effort would require a great amount of detail and is unlikely to affect the question of where ATARS is to be located.

B-3.1 Target Report Delivery Delays

One factor which does enter the cost analysis concerns the amount of information that must be transmitted to ATARS within a short time. For ATARS at the DABS site, supply of target reports takes place almost instantaneously with the reports being written into the shared global memory. With ATARS at the ATC facility, these reports form a queue to be sent to the ATC location. The engineering model design, built to the DABS ER specifications, provides a minimum transmission capacity of 9600 bps for this surveillance data. Under high instantaneous loading of the sensor, as would occur when 400 aircraft are found within an azimuth wedge of 90 degrees, surveillance data generation exceeds this transmision capacity resulting in a time delay while the data waits in the queue. Since this delay is short, it may be unimportant to ATC operations which proceed more slowly with communications between the controller and the aircraft available at any time. For ATARS, however, even a short transmission delay can result in a more substantial delay in uplink of an advisory which must wait until the DABS antenna again points in the correct direction. This transmission delay may result in selection of ATARS resolution advisories based on older data when more recent data has actually been measured by the sensor. The use of older data can be particularly degrading if aircraft re maneuvering at the time of conflict detection

Figure B-3-1 illustrates a typical case of delay in delivering ATARS advisories that could occur under high sensor loading. Events occurring during one scan of the antenna are indicated by circled letters. The antenna rotates clockwise. The circled letters are placed at the azimuth that the antenna would have when the corresponding event occurs. The situation portrayed in Figure B-3-1 involves a conflict between two aircraft not in ATARS seam areas. (Seam areas are areas of overlapping coverage between two ATARS sites in which multi-site coordination must be conducted

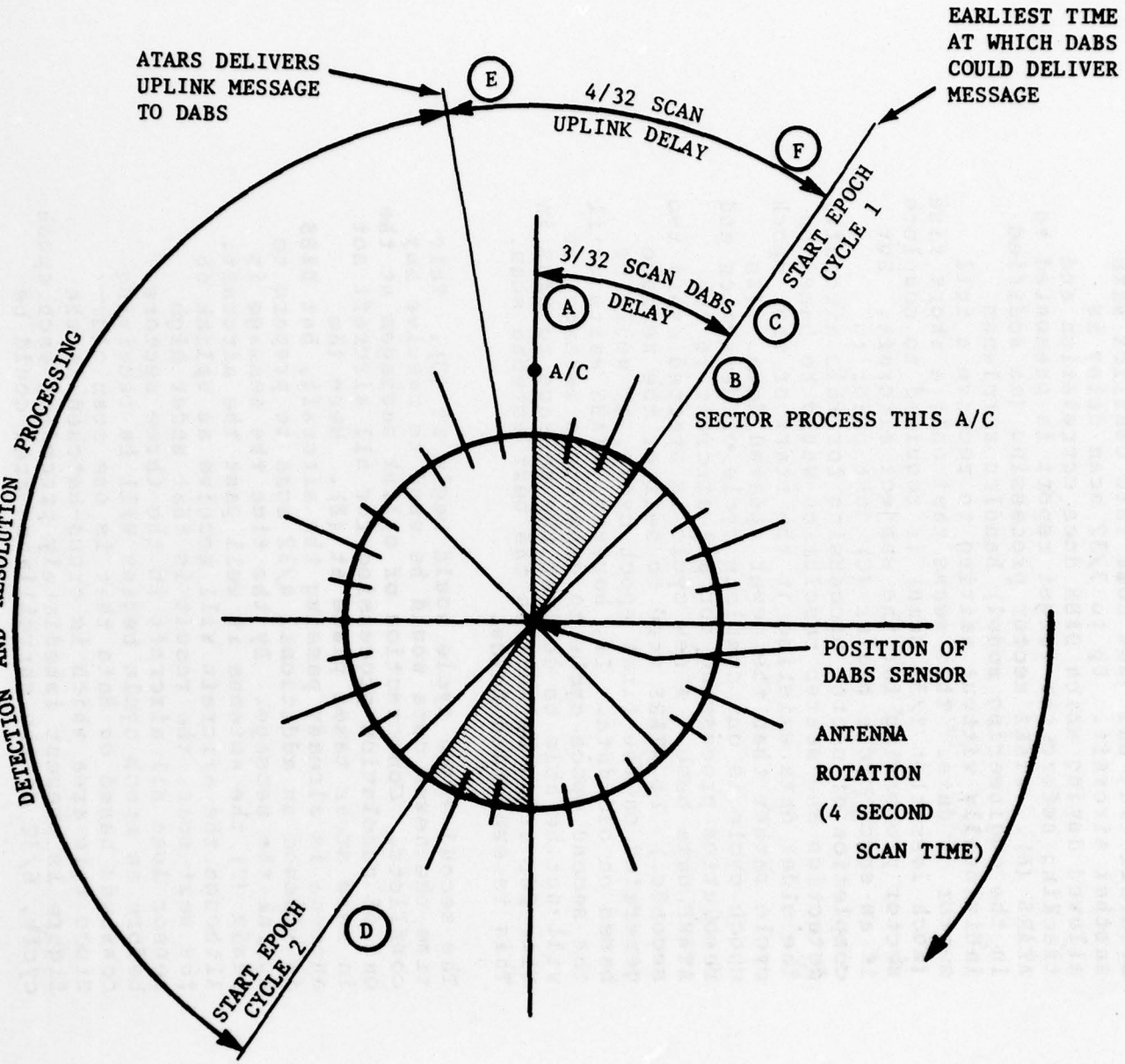


FIGURE B-3-1
ATARS EVENT SEQUENCE FOR CONFLICT NOT IN SEAMS

for resolution advisories.)

At (A) the DABS antenna passes the subject aircraft that has just come into conflict with another aircraft. Up to 3/32 scan delay is allowed during which DABS does correlation and tracking before the target report is presented to ATARS (B). ATARS sector processing (as modified in the engineering model) handles airplanes individually without waiting to receive a full sector of data. This means that only a short time (much less than 1/32 scan) is required to complete sector processing for the subject aircraft. But if an epoch cycle begins (C) just prior to completion of sector processing for this aircraft, detection and master resolution would be based on the older data existing at the start of that epoch cycle rather than the newer updated data. (An epoch cycle is one complete cycle of detection and resolution processing for all aircraft in the ATARS data base. A new cycle is started every two seconds.) If ATARS were to deliver the message generated on the first epoch cycle, it would be based on old data. If, however, ATARS waits until the second epoch cycle to generate a message, it will not be able to deliver the message to DABS in time for it to be sent on the next antenna scan. This is explained below.

The second epoch cycle would begin at (D). This time the newer data would be used to resolve any conflicts. Construction of uplink messages at the end of resolution processing for all aircraft not in seam areas takes place at (E). Here the antenna is already passing the aircraft, but DABS is allowed an additional 4/32 scan to prepare to uplink the message. By the time the message is ready (F) the antenna is well past the aircraft. Although the aircraft will receive an uplink on the next scan, the result is that under high sensor load all aircraft in the three sectors before an epoch cycle begins will be receiving commands based on data that is one scan old. Since this area which is cross-hatched in the figure is present immediately preceding each epoch cycle, 6/32 of the surveillance area could be

affected.

If the sensor were not fully loaded, then detection and resolution could be completed at some point prior to (E). If the load is sufficiently light, there will be time for DABS to deliver the message on the next scan and no aircraft will receive messages based on old data.

For aircraft in the seams the situation is worse since seam processing must wait until almost the end of the two-second epoch cycle. Figure B-3-2 shows the situation for seam conflicts. ATARS would deiver the uplink message to DABS at (E) in this figure and the sensor would not be able to deliver the message before point (F). The areas where aircraft in the seams would receive advisories based on old data are shaded in Figure B-3-2.

For an antenna with a 4.7 second rotation period these effects are somewhat mitigated, with a reduction in the size of the shaded areas, but any further delay in receipt of target reports would increase the total area where old data is used by about 14 sectors per second of delay.

The purpose of this discussion of delivery delays was to indicate that even the current ATARS multi-site design is subject to delivering advisories based on old data when the sensor is operating to capacity or conflicts occur in the seams. It is thus clear that any additional delay in receiving target reports from DABS will have the undesirable effect of increasing the area in which advisories will be delivered based on old data.

B-3.2 Duplication of Equipment

Another item affecting the cost of the two alternatives is duplication of equipment. In the current engineering model design, ATARS and DABS share several system hardware components including global memory, power supply cabinets, and communications processors. For ATARS at the ATC facility some duplication of these components

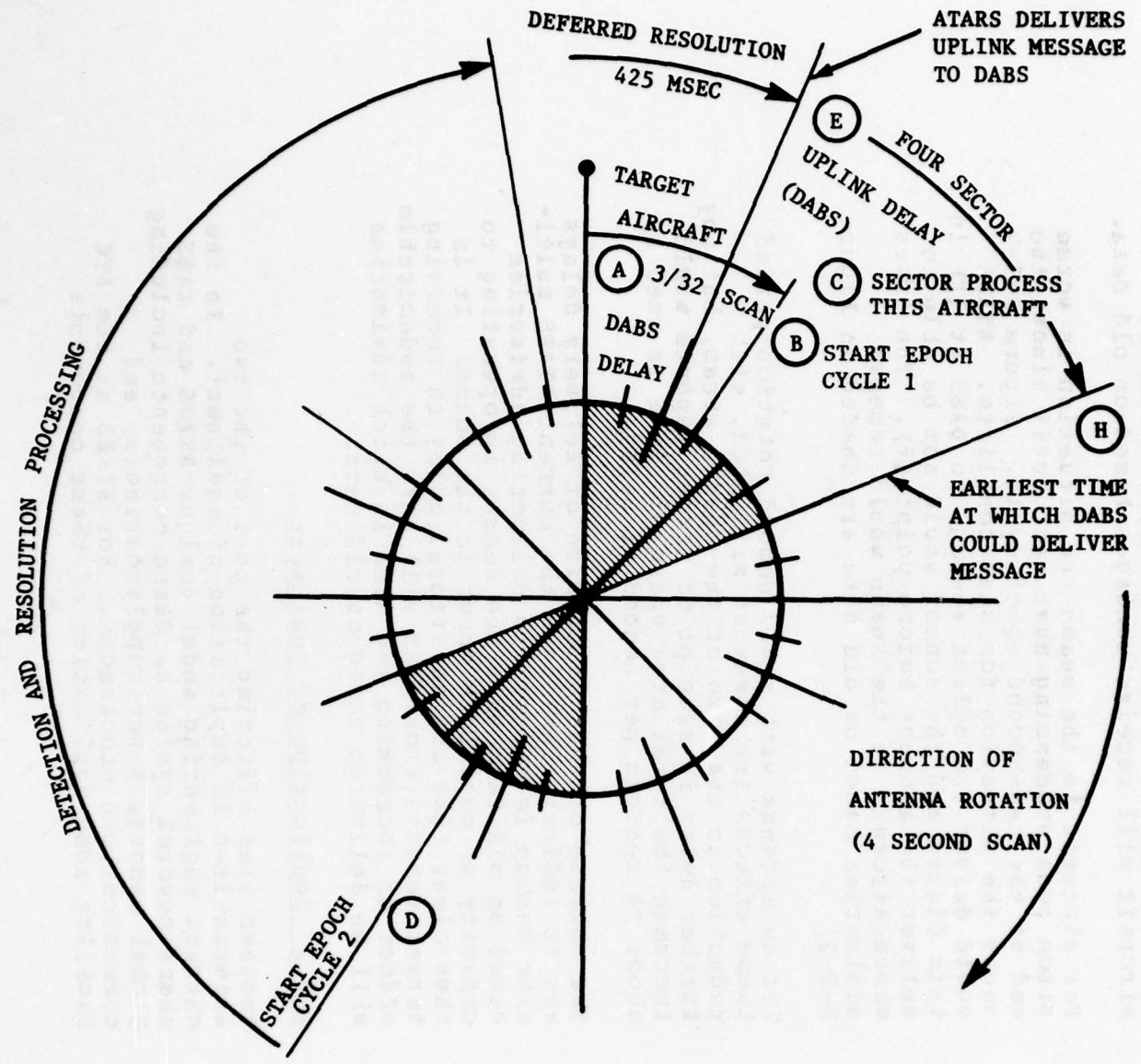


FIGURE B-3-2
ATARS EVENT SEQUENCE FOR CONFLICT IN THE SEAMS

would be necessary without significant reduction in the size, number or cost of components at the DABS site. In particular removal of the 8 ATARS micro-processors from the DABS site is not expected to significantly reduce the cost of the power supply required there, but will require addition of a power supply to run the processors at the ATC facility. Similarly, communications processors will have to be added to the facility-located ATARS to handle the incoming surveillance data. These will have to write a copy into global memory for ATARS use, and forward a copy to ATC computers for standard ATC operations. Since the surveillance data received by the computers will have been sent by their counterparts at the DABS site, no reduction in the number of processors located there is likely. This trend toward duplication, found throughout the facility-located ATARS system, increases the total amount of hardware and software, diluting the maintainability benefit gained by reducing the number of components at the remote location.

Even when ATARS equipment can be moved from DABS to ATC without duplication, the effect on the total amount of equipment at the DABS site is small. For example, the 7 ATARS micro-computers containing ATARS programs make up only 25% of the total DABS complement of 28 active microcomputers. Furthermore, microprocessors make up only a portion of the total equipment at the DABS site. Therefore, relocating ATARS to the ATC facility will not significantly reduce the total amount of equipment at the DABS site.

B-3.3 Duplication of Software

A similar trend is found with respect to the software. Current projections for ATARS indicate an expected size of about 35 thousand words for primary program storage. The total amount of DABS software runs to about 180 thousand words so that ATARS accounts for only 20% of that total software. While it may be possible to produce a hardwired version of DABS to eliminate software at remote facilities, there are several major

disadvantages to this. Foremost among them is that great flexibility would be lost in changing program parameters and logic and in adapting the algorithms to local conditions as is required for example with the surveillance maps. Another important consideration is cost. A hardwired DABS would require considerable re-design, and would probably be subsantially more expensive than a software driven version.

As intermediate points between hardwired DABS and the current engineering model, a software driven production model DABS could be built incorporating read only memories (ROM), programmable read only memories (PROMS), erasable and programmable read only memory (EPROMS) or non-volatile random access memory (RAM) instead of the volatile RAM used in the current design. These memories provide different degrees of program protection and ease of modification.

PROMS and EPROMS are different from the volatile RAM used in the engineering model in that the contents of memory are not lost when power is shut off; rather the programs and data stored in the memory are retained and are available when power is restored. This means that a new program does not have to be loaded from an external source after a power failure. Flexibility and cost savings are provided, however, by making these memories user programmable on a special external PROM programming device.

EPROMS are re-usable. When a program change is desired the old program is erased by exposing the EPROM to ultraviolet light, and then the new program is loaded by reprogramming the EPROM on the PROM programmer. Standard PROMS are initially programmable on the PROM programmer, but these cannot be re-used and must be replaced with a new PROM when a program change is desired.

ROM's are similar to standard PROMS except that they are not user-programmable but are specially designed at the micro circuit level to contain specific instructions. Because these cannot be

changed and because of their higher cost ROMS are used only for program segments that are very likely to remain constant.

Of the different options probably the one most suited for DABS global memory is the non-volatile RAM. Like the EPROM, PROM and ROM the contents of memory are retained during power interruptions so that programs do not have to be re-loaded after power failures. In addition, this type of memory is quite easy to modify. When a change is desired, new programs can be loaded from an external device without physically removing the memory from DABS.

With these different memory options available, it is expected that DABS will continue to be software driven. If this is the case, then inclusion of ATARS software at the DABS site does not substantially increase the complexity of the remote system. As designed, a failure of ATARS does not affect the operation of DABS. In fact, having the extra ATARS computers available allows DABS to continue operation by shutting off ATARS if the operability of DABS surveillance processing is in jeopardy from computer failure. This means that location of ATARS at the DABS site could actually tend to increase the reliability of the other DABS functions.

Support for this position comes from historical evidence suggesting that hardware failure is a much greater cause for concern than software failure. In a recent Federal Aviation Administration (FAA) report (Reference 4) total unscheduled ARTS downtime for 63 facilities nationwide was reported to total 1381 hours for the period 7/76 to 6/77. Software failures accounting for 35 hours of this amounted to only about 2.5% of that total. Of the remaining downtime, equipment failure accounted for 1070 hours, or about 77% of the total. This would indicate that even in a manned system such as ARTS, where operator intervention is possible, software failures can be made small relative to the number of hardware outages.

ATARS has been designed with remote, unmanned, operation in mind, and is expected to have a higher reliability than ARTS. ATARS is estimated to have a Mean Time Between Outage (MTBO) due to all causes of 23,753 hours for the fully redundant system compared to only 780 hours MTBO (unscheduled causes) exhibited by the ARTS equipment. Furthermore, special care has been taken to protect against transient Central Processing Unit (CPU) or memory failure that could go undetected in traditional periodic maintenance.

B-3.4 Accessibility for Maintenance

One point that has been raised as a potential benefit of locating ATARS at ATC facilities is lower maintenance cost resulting from reduced travel time necessary to make repairs and perform maintenance checks. While this may be a significant factor at long range installations, it is not at terminal facilities where the radar head is typically located on airport property and can be reached by a perimeter road after only a few minutes travel. (There are exceptions such as Tampa/Sarasota.) Furthermore, the majority of facilities in high density areas where a failure is most critical are terminal facilities. Overall in 1976 there were almost twice as many terminal facilties as enroute facilities, with a higher percent of the terminal facilities located in heavily traveled areas. For these reasons, the value of reduced travel time has been discounted in this analysis as a rationale for choosing an ATARS location.

B-3.5 Backup for Catastrophic ATC Failure

While every effort has been made to define the two configurations for the location of ATARS so that they would have equal performance, it has been impossible to do so where protection in event of catastrophic ATC failure is concerned. Performing ATARS calculations in dedicated computers at the ATC facility can offer ATARS protection in event of failure of the ATC computer or controller displays. However, there are some catastrophic

failures, such as those caused by sabotage, lightning strikes or an aircraft crash into the building housing the ATC facility, that could disable both ATABS and the ATC system simultaneously. Simultaneous failure of ATARS and ATC could also be caused by any failures that would affect all of the DABS to ATC surveillance lines.

While it is difficult to evaluate quantitatively, there is a clear advantage, from an ATC backup point of view, to implementing ATABS at the DABS site. Providing backup collision avoidance protection when the ATC system experiences a catastrophic failure is an important role for ATARS. This role is carried out most effectively when ATARS is implemented at the DABS site and is physically removed from the ATC facility.

B-4. QUANTITATIVE COST DIFFERENCES

The last section presented several qualitative differences between the facility-located and the site-located ATARS. Here, these differences will be developed further with inclusion of cost estimates for some components. The predominant costs fall into two categories: costs associated with additional surveillance communications and costs associated with hardware duplication for the facility-located ATARS. Maintenance differences between the two systems make up another smaller category of costs which is also discussed but not costed.

B-4.1 Surveillance Communications

In the first category, high instantaneous data generation rates resulting from a sensor loading of 400 aircraft in 90 degrees, exceed the transmission capacity of the DABS to ATC surveillance links. While this may not be a problem for traditional ATC operations, time delays play an important part in ATARS operation. Generation of ninety-one bit beacon reports for each aircraft is responsible for 36,400 bits of data when 400 aircraft are found in 90 degrees. Addition of 13 bit idle characters required between ground-line transmission of each beacon report increases this to 41,600 bits. Assuming an additional 10% for uncorrelated radar reports, map, timing and strobe messages brings the total amount of data generated to 45,760 bits.

B-4.1.1 En Route Radar Considerations

If the antenna rotation rate is 5-6 rotations per minute, (as is the case for en route radars) this means that between 2.5 and 3 seconds are required to sweep out the 90 degree sector containing the 400 aircraft. For an antenna rotating at six rpm (2.5 seconds to sweep out 90 degres) this yields a data generation rate of 18 thousand bits per second (15 thousand for the five rpm antenna.) These data generation rates exceed the line capacity given by the three 4800 bps lines

specified in the ER by six to 27 percent.

Since all DABS sites nationwide will not handle 400 aircraft (even though the system has been designed for that maximum) it may be reasonable to consider that the the cost of this extra communications load is distributed across all sites, arriving at a cost differential for a hypothetical ARTCC. At some sites, the three 4800 bps lines will supply sufficient capacity to handle the DABS to ATC surveillance data without delay and another surveillance transmission line will not be required. At other, busier, sites the standard lines will not be sufficient to handle the surveillance without buffer delays, and addition of another line wll be required. Although up to 378 aircraft can be handled in 90 degrees for an antenna scan time of 12 seconds, only 315 aircraft can be handled in 90 degrees with an antenna scan time of 10 seconds. Loadings up to these limits can be handled by a sensor without delay utilizing the three transmission lines specified in the ER.

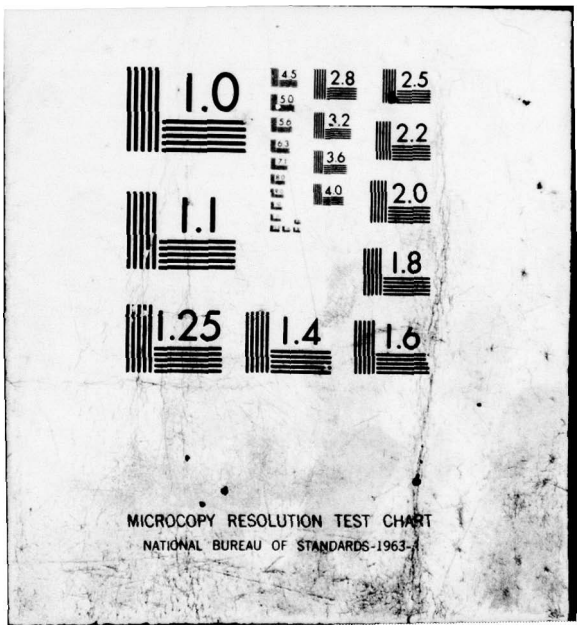
However, because a back-to-back antenna arrangement is used to increase the effective scan rate, data from both front and back faces must be sent to ATARS. For the site-located ATARS this means that both the aircraft in the front face and those in the rear face must be counted when determining the total amount of data generated while the antenna sweeps through 90 degrees. Under current specifications this is not a major consideration in determining the effect of maximum sensor loading on relocating ATARS to the facility, because the most stringent sensor performance requirement (400 aircraft in 90 degrees) also implies (since the maximum total sensor load is 400 aircraft) that no additional aircraft can be seen by the other antenna face.

If ATARS were implemented at the DABS site, only data from the front face (46 thousand bits) might go to ATC. (Today, ATC only has available data from one antenna face. Whether or not a decision would be made in the future to provide both

AD-A077 713 FEDERAL AVIATION ADMINISTRATION WASHINGTON DC OFFICE--ETC F/G 17/7
REPORT OF THE FAA TASK FORCE ON AIRCRAFT SEPARATION ASSURANCE. --ETC(U
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

streams of data to ATC cannot be determined at this time.)

The general effect of the back-to-back antenna is that the average transmission line utilization is increased. For the same number of aircraft uniformly distributed throughout the airspace, the transmission lines will be required to carry twice as much data as for a single face antenna to serve ATARS at the facility. While this does not influence the theoretical requirement for number of transmission lines (as long as the bunching requirement is more strict) it could be important when considering the number of lines actually put in service.

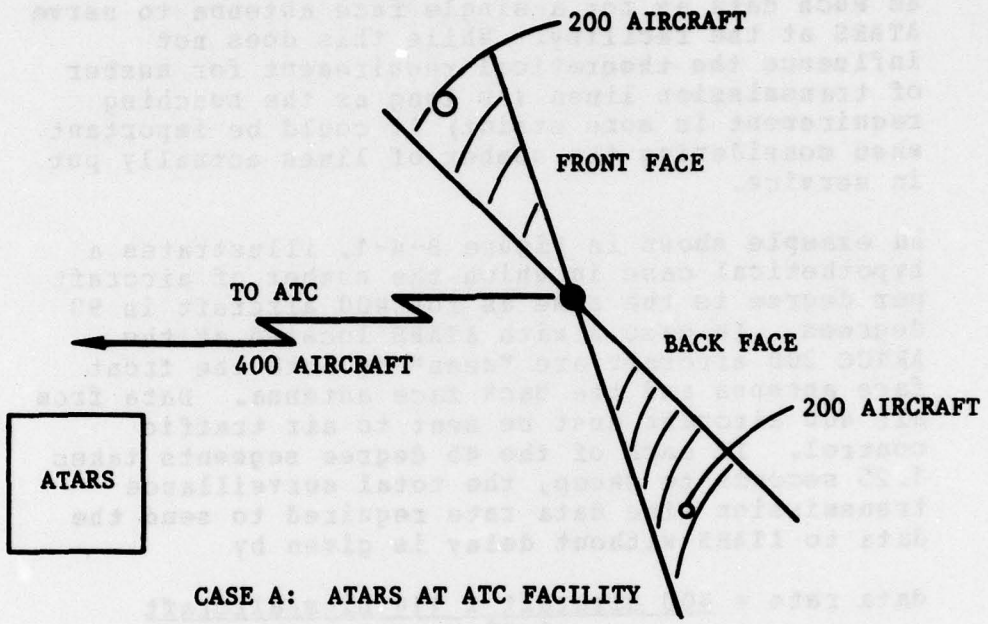
An example shown in Figure B-4-1, illustrates a hypothetical case in which the number of aircraft per degree is the same as for 400 aircraft in 90 degrees. In case A with ATARS located at the ARTCC 200 aircraft are "seen" by both the front face antenna and the back face antenna. Data from all 400 aircraft must be sent to air traffic control. If each of the 45 degree segments takes 1.25 seconds to sweep, the total surveillance transmission line data rate required to send the data to ATARS without delay is given by

$$\text{data rate} = \frac{400 \text{ aircraft} \times 114 \text{ bits/aircraft}}{1.25 \text{ seconds}}$$

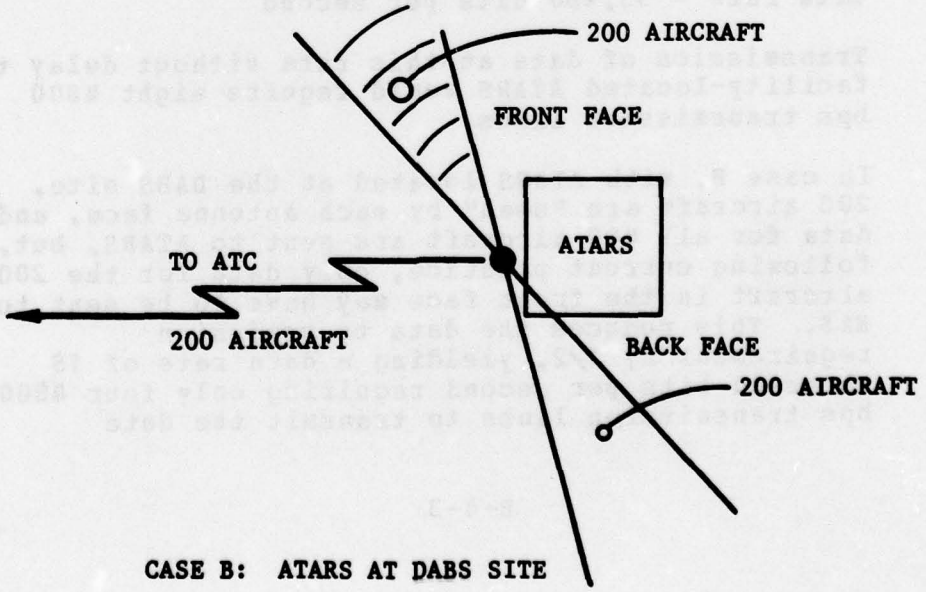
data rate = 36,480 bits per second

Transmission of data at this rate without delay to facility-located ATARS would require eight 4800 bps transmission lines.

In case B, with ATARS located at the DABS site, 200 aircraft are "seen" by each antenna face, and data for all 400 aircraft are sent to ATARS, but, following current practice, only data for the 200 aircraft in the front face may have to be sent to NAS. This reduces the data transmission requirement by 1/2, yielding a data rate of 18 thousand bits per second requiring only four 4800 bps transmission lines to transmit the data



CASE A: ATARS AT ATC FACILITY



CASE B: ATARS AT DABS SITE

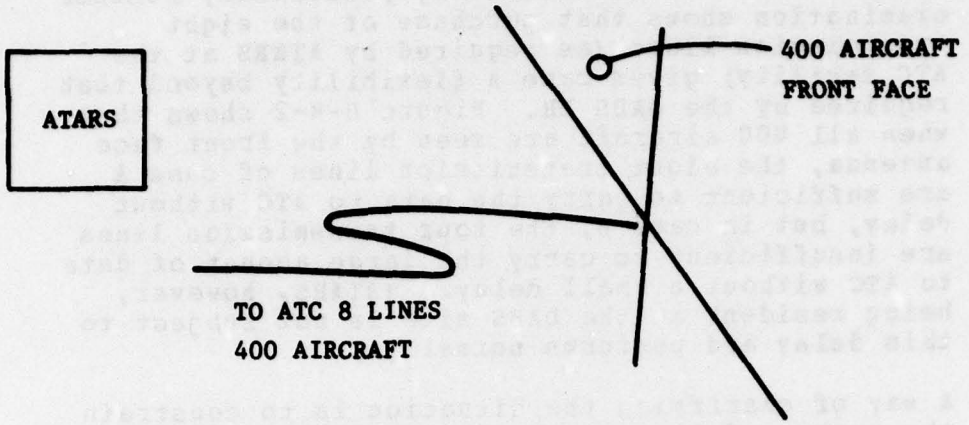
FIGURE B-4-1
DATA TRANSMISSION FOR BACK-TO-BACK ANTENNAS

without delay. If a small delay were acceptable to ATC then three 4800 bps lines would suffice.

Although it seems from this discussion that ATARS at the DABS site is definitely preferable, further examination shows that purchase of the eight transmission lines (as required by ATABS at the ATC facility) gives case A flexibility beyond that required by the DABS ER. Figure B-4-2 shows that when all 400 aircraft are seen by the front face antenna, the eight transmission lines of case A are sufficient to carry the data to ATC without delay, but in case B, the four transmission lines are insufficient to carry the large amount of data to ATC without a small delay. (ATARS, however, being resident at the DABS site is not subject to this delay and performs normally.)

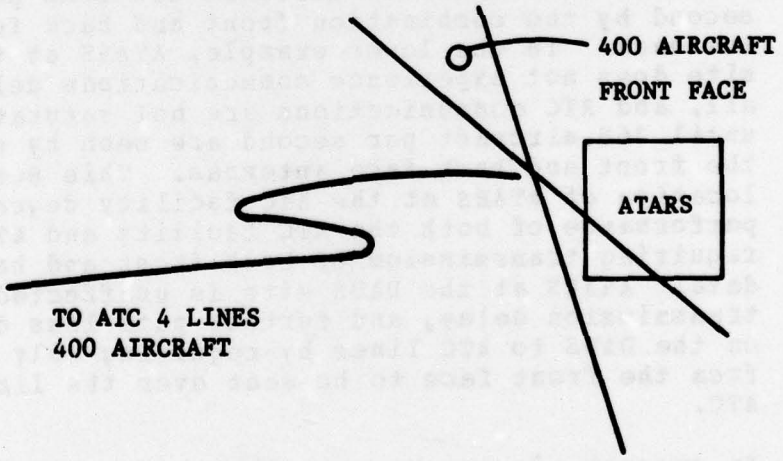
A way of clarifying the situation is to constrain the number of lines to be constant, fixing the cost, and to examine the difference in performance associated with the two systems. The upper part of Figure B-4-3 shows ATARS at the ATC facility connected to DABS by four transmission lines. In the bottom part of the figure, the ATC facility is connected to the joint ATARS/DABS site by four lines also. Transmission capacity for the lines in the upper example will be completely saturated whenever more than 168 aircraft are seen per second by the combination front and back face antennas. In the lower example, ATARS at the DABS site does not experience communications delays at all, and ATC communications are not saturated until 168 aircraft per second are seen by each of the front and back face antennas. This means that location of ATARS at the ATC facility degrades the performance of both the ATC facility and ATARS by requiring transmission of both front and back face data. ATARS at the DABS site is unaffected by transmission delay, and further puts less demand on the DABS to ATC lines by requiring only data from the front face to be sent over the lines to ATC.

In summary, it can be said that under the present bunching and maximum surveillance specifications



CASE A: ATARS AT ATC

EIGHT LINES GIVE 38,400 BPS CAPACITY TO TRANSMIT DATA WITHOUT DELAY



CASE B: ATARS AT DABS SITE

FOUR LINES GIVE 19,200 BPS CAPACITY, YIELDING A WORST CASE DELAY OF ABOUT 1 SECOND

FIGURE B-4-2
SYSTEM PERFORMANCE UNDER BUNCHING

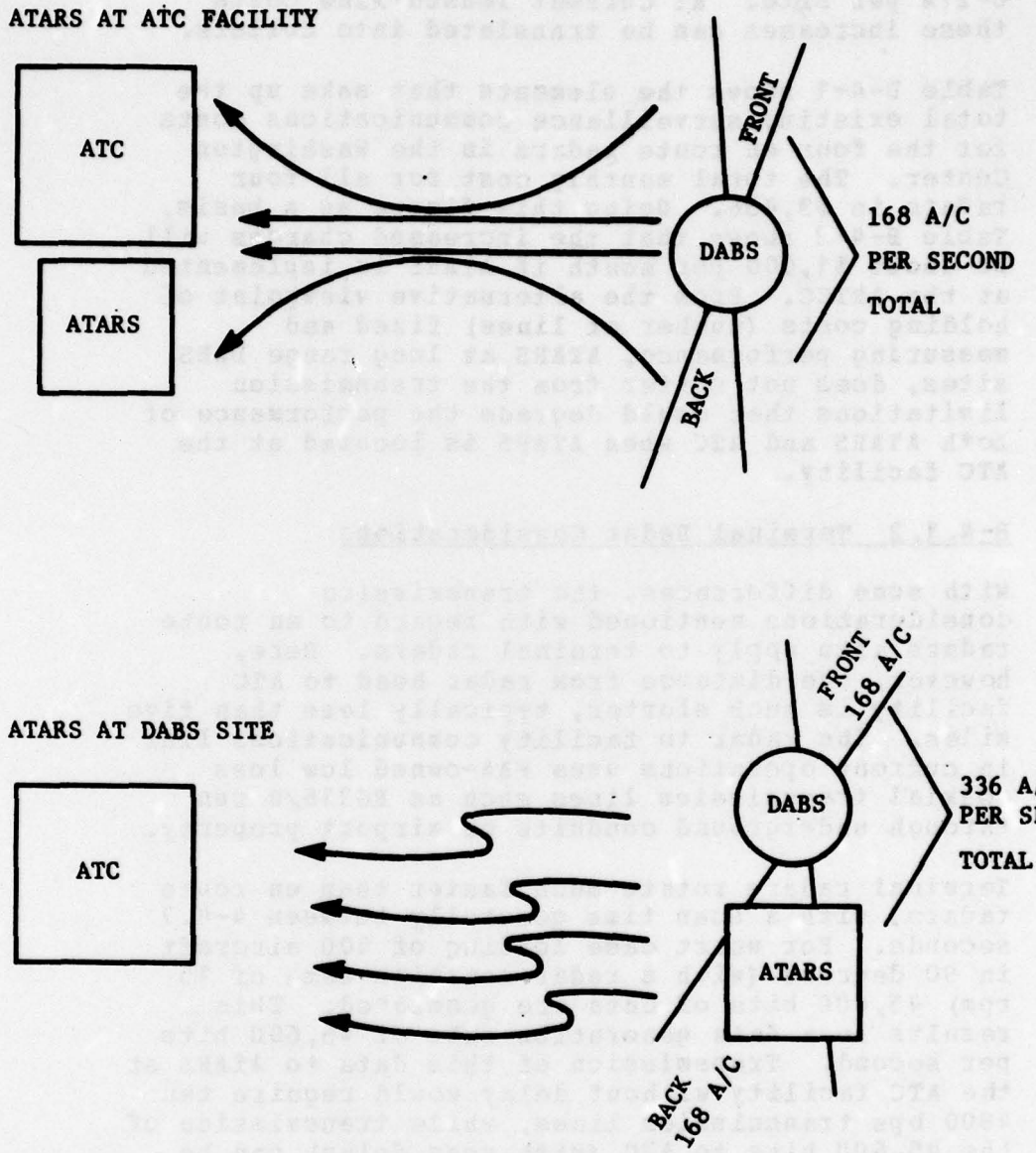


FIGURE B-4-3
CONNECTING TRANSMISSION LINES DO NOT FORM A BOTTLENECK FOR SITE-LOCATED ATARS

for 400 aircraft, location of ATARS at the ARTCC will increase the surveillance data transmission requirement using 4800 bps voice grade lines by 6-27% per site. At current leased-line costs these increases can be translated into dollars.

Table B-4-1 shows the elements that make up the total existing surveillance communications costs for the four en route radars in the Washington Center. The total monthly cost for all four radars is $3,456. Using this figure as a basis, Table B-4-2 shows that the increased charges will be about $1,000 per month if ATARS is implemented at the ARTCC. From the alternative viewpoint of holding costs (number of lines) fixed and measuring performance, ATARS at long range DABS sites, does not suffer from the transmission limitations that could degrade the performance of both ATARS and ATC when ATARS is located at the ATC facility.

B-4.1.2 Terminal Radar Considerations

With some differences, the transmission considerations mentioned with regard to en route radars also apply to terminal radars. Here, however, the distance from radar head to ATC facility is much shorter, typically less than five miles. The radar to facility communications link in current operations uses FAA-owned low loss coaxial transmission lines such as RG216/U run through underground conduits on airport property.

Terminal radars rotate much faster than en route radars, with a scan time generally between 4-4.7 seconds. For worst case loading of 400 aircraft in 90 degrees (with a radar rotation rate of 15 rpm) 45,600 bits of data are generated. This results in a data generation rate of 45,600 bits per second. Transmission of this data to ATARS at the ATC facility without delay would require ten 4800 bps transmission lines, while transmission of the 45,600 bits to ATC (with some delay) can be accomplished by three 4800 bps voice grade lines similar to those leased from the telephone company for long range radar use. One particularly costly

TABLE B-4-1

MONTHLY TELECOMMUNICATIONS COST ESTIMATES FOR 4 ARSR RADARS

EQUIPMENT COSTS	
One Time Fixed Costs	
Station Terminal Installation	$100
Purchase of Modems (4800 BPS) (2)	9600
Sub Total: Fixed Costs	$10,608
Amortized Over 240 Months	45
Recurring Monthly Charges	
Station Terminal Rental (2)	50
C1 Conditioning	5
Sub Total: Recurring Charges	55
Total Per-Circuit Monthly Costs Not Including Line Charges	$100
Cost for 4-3 Circuit Lines	$1200

Line Charges (Per 4800 bps Circuit, Per Month)	
Line 1: Leesburg to Suitland ARSR 40 Miles	108
Line 2: Leesburg to Roanoke ARSR 162 Miles	201
Line 3: Leesburg to Raleigh ARSR 270 Miles	248
Line 4: Leesburg to Cape Charles ARSR 151 Miles	$195
Subtotal: Cost for Single Circuits	$752
: Cost for 3 Circuit Lines	2,256
TOTAL: SUM OF MONTHLY EQUIPMENT AND LINE CHARGES	$3,456

TABLE B-4-2

SURVEILLANCE RELATED DATA TRANSMISSION COSTS

PER SITE	DABS-LOCATED ATARS	ATC-LOCATED ATARS
Maximum No. Aircraft	400	400
Bunching in 90°	400	400
Bits Generated in 1/4 Scan	40,040	40,040
Total Bits Transmitted	45,760	45,760
Time to Transmit Data to ARTCC	10 Sec	2.5 Sec
No. of 4800 BPS Lines Required (3 are standard)	1	4
% Increase Above Standard Data Transmission Rate	0%	27%
COST INCREMENTS		
Monthly Cost (4 ARSRs Supporting Washington Center) (Based on 27% Increase In Number of Lines Above Standard)	$0	$933*
Monthly Cost (4 ARSRs Supporting Washington Center) (Based on 33.3% Increase in Number of Lines Above Standard)	$0	$1152*

* COSTS CALCULATED USING TELCO TARIFF NO. 260.

item associated with use of lines of this type is the modems necessary for transmission of digital data. One modem is required on each end of each data line, so that the baseline case employs six 4800 bps modems available commercially at a cost of about $1 per bps (Reference 3) for a total cost of about $29,000. The ten lines required for ATARS at the ATC facility would use 20 modems costing approximatly $96 thousand for an increased cost of $67 thousand per site over ATABS at the DABS site. Added to this would be facility dependent costs of purchase and installation of the seven additional lines.

These per site costs are quite high. Fortunately another alternative, using the existing RG216/U coaxial lines is available for providing surveillance communications. These lines, presently used for radar video transmissions, have a very wide bandwidth capable of supporting rapid digital data communications. As with all coaxial cable, transmission line losses are a major consideration. However, the RG216/U is a low loss type of coaxial cable having an attenuation of about .1 db per 100 feet when operating at the required data transmission rate (about 100 mc). With a transmission length of five miles (26,400 feet) the total loss in the line would be 26.4 db, yelding an output signal strength of approximately 1/500th of the input power. This is quite small and may require amplification. However, for an installation such as Washington National Airport where the radar is only 1/2 mile away, the loss is only 2.64 db, representing an acceptable power in to power out ratio of 1.84. Commercially available 56,000 bps modems specially designed for use with coaxial cable could be connected to each end of the line at a cost of $6500 each.

Use of existing coaxial lines that will no longer be needed for video transmission with introduction of DABS represents an attractive alternative to installation of audio type digital data cables. At new installations, of course, higher cost would be associated with providing the better quality video line rather than less expensive audio type

lines.

Use of a coaxial transmission line would supply sufficient capacity for increased numbers of aircraft. The bandwidth of these lines is so large that their use is effectively limited by the modems and computer processing capability rather than the line itself.

Advantages and disadvantages associated with use of the back-to-back antenna, of course, do not apply to terminal ATARS which uses only a front face antenna. Similarly, use of coaxial transmission lines in the en route surveillance system would be unlikely due to high losses and costs over the distances involved. Although some advantages of large bandwidth transmission for long distances could be obtained through the use of microwave transmission, this is inconsistent with current FAA policy and was not investigated.

B-4.2 Equipment Costs

In addition to the cost of communications lines for surveillance transmission there are some differential costs for equipment associated with facility-located ATARS. These derive from duplication and loss of economics of scale in the purchase of two separate components rather than a single unified DABS/ATARS complex.

In determining appropriate costs of duplication some attempt has been made to predict to a certain extent exactly what type of equipment would be associated with a production model ATARS. The current engineering models, for example, require ten cabinets for component mounting. With development and use of specially designed circuit boards rather than the standard commercial boards now used, less space would be taken up inside each cabinet. The total size could be reduced considerably, probably by a factor of 1/2. The computer complex now requiring several cabinets could be reduced to a single cabinet. Use of larger increments of computer memory and specialized computer boards would also contribute

to a reduction in power requirements, reducing cost and space requirements for power supplies. Finally, specialized communications equipment designed for test and evaluation would not be required.

Each cabinet of the engineering model complex has its own five volt power supplies. The model used is a regulated 150 amp LH Research model MM301 OP/115 derated to 100 amps by the contractor. Three supplies are combined for reliability, in such a manner that failure of a single supply will not cause failure of the complex. The power supply is commercially available from LH Research at a cost of $625 with reductions for quantity purchases. A reduction in the size of the computer complex hardware of 29% could result in a reduction of the power supplies currently used to power the computers by a similar amount. If this were the case, high reliability could be maintained by substituting smaller 100 amp units for the 150 amp units now used at the DABS site. The power to run the ATARS computers could be supplied by three, 50 amp units located at the ATC facility. These are currently available from LH research for $540 and $380 respectively. As can be seen, a combination of smaller power supplies would cost more than a single, larger power supply.

The most costly duplication of equipment occurs with computer components. In the engineering model three computers are provided to handle all external communications with ATC and other sensors. These computers are responsible for receiving requests and acknowledgements from other sensors and for managing inter-sensor and surveillance communications. An increase in the rate at which surveillance data is sent would put a further load on these computers. Moreover, with ATARS located at ATC facilities, additional computers would be required to receive the surveillance data sent from the DABS site, supplying a copy to ATARS and forwarding a copy to the ATC computer.

This task could be performed by existing ARTS or NAS computers, but should not be because of reliability considerations. The computers distributing the DABS data must be made especially reliable, as they form a reliability bottleneck for both the DABS/ATARS system and traditional air traffic control.

Each computer in the engineering model is composed of four computer boards including two two-sided CPU boards, one ten-layer, CPU-voter board and one eight-layer Bi Polar Memory board. The CPU boards are available now at a commercial cost of $1000 each. The voter boards and memory boards each holding approximately 250 integrated circuits, are not currently available but were constructed specifically for DABS. The cost of a production model board performing the same functions but reduced in size is estimated to be at least as much as the CPU board. The total cost, then, of a single DABS voting computer would be about $4000. If three additional computers were required at the receiving end as well as the original three at the sending end, the $12,000 cost of these extra computers would be attributable to the cost of ATARS at the ATC facility.

Overall, the costs in this section have been based on commercially available components applied in construction of the engineering model DABS. While a general cost reduction could be expected for production models, the trends behind the cost differences would continue to hold true. That is, a production model DABS based on the current engineering model concept would probably contain specially designed voting computer systems arranged on a single board, memory in the largest available quantities, and smaller power supplies. This would tend to reduce the overall cost of a production model from that indicated here, while maintaining a lower overall equipment cost for ATARS at DABS sites.

B-4.3 Cost Summary

In summary, although ATARS at the ATC facility is

technically possible, duplication of equipment, loss of economies of scale and increased communications result in higher costs for ATABS at ATC facilities. For a terminal site the increased costs include $13,000 for computer hardware. Most of this is due to additional computers to handle and distribute the incoming DABS surveillance data, with cabinets and power supplies making a smaller contribution. Increased costs for the modems would range from $67,000 per site for purchase of voice grade modems to $13,000 for purchase of special high bit rate modems designed for use with coaxial cable. Cable costs, maintenance and installation are extra.

For en route sites, the hardware costs would be the same, but the communications costs would vary between an increase of 33% and an increase of 0% depending on the load of the sensor. For the Washington center a 33% increase amounts to about a total $12,000 per year for all four radars.

B-5. CONCLUSIONS

1. This study has concluded that it would be technically feasible to provide ATABS service from either the DABS sites or the ATC facilities. There are some advantages to either alternative. However, location at the DABS site is preferred primarily because ATABS is not then subjected to additional queuing and transmission delays in receiving surveillance data or sending uplink messages. Factors strongly influencing the location decision are transmission and hardware costs.

2. ATARS implemented at the DABS site provides a backup protection capability in event of catastrophic failure of the ATC facility, that cannot be effectively matched by ATARS implemented at the ATC facility.

3. Location of ATARS at the ATC facility (ARTCC or tower) does not significantly reduce the amount of hardware or software at the radar site since ATARS comprises only 25% of the total DABS software and an even smaller percentage of the total hardware.

4. Transmission of rapidly generated surveillance data to ATARS located in tower equipment rooms using standard voice grade lines would require ten 4800 bps transmission lines to insure that no additional delays are added to ATARS while fulfilling the DABS ER requirement for processing 400 aircraft in 90 degrees. This is seven more lines than currently specified in the DABS ER. For terminal sites designed to handle the specified 400 aircraft, the increase in capital cost to support the seven additional transmission lines would exceed $60 thousand per site.

5. Use of very high data rates and low loss coaxial cable at some existing terminal sites could reduce the incremental cost of transmitting surveillance data to facility-

located ATARS to $13,000 per site.

6. Depending on the rotation rate of the long range radar antenna (10-12 sec.) location of ATARS at the ARTCC rather than at the DABS site will increase the demand on leased transmission lines by a minimum of 6-27%. This increase is incurred in meeting the DABS ER requirement for processing a total of 400 aircraft (all located in a 90 degree sector) without data transmission delays unacceptable to ATARS. If all sites were equipped to handle 400 aircraft, the cost to the FAA would increase by a factor of 1/3 through the provision of 4 rather than 3 surveillance transmission lines. This would be a total increase of approximately $1,000 per month for leased surveillance lines for 4 radars serving the Washington center.

7. The need for ATARS to have a rapid data rate from front and back antennas increases average line utilization from long range radar sites. Location of ATARS at the DABS site would lower average line utilization (compared to ATARS at the ARTCC) for ARTCC's requiring only front face surveillance data.

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APPENDIX C

DEVELOPMENT OF AN INTERFACE BETWEEN ATARS AND BCAS

C. F. Swett

C-1. INTRODUCTION

Since the Automatic Traffic Advisory and Resolution Service (ATARS) (References 1 and 2) and Beacon Collision Avoidance System (BCAS) (References 3 and 4) both form a part of the integrated separation assurance system, an interface between them must be provided which will enable the two systems to operate in a cooperative manner. The purpose of this appendix is to describe the concept for the necessary interface, to present computer decision logic which defines it in detail, and to identify the changes required to existing systems to implement the interface.

C-1.1 The ATARS and BCAS Systems Under Study

The ATARS system to be interfaced with BCAS is described in Reference 2. This interface study was originally conducted to provide an interface between ATARS and the BCAS represented by Reference 3. This BCAS operates in several different modes. Whenever a sufficient number of ground sensors is available, BCAS is able to obtain full, accurate surveillance on intruders and can issue either horizontal or vertical resolution advisories. The BCAS obtains surveillance in a passive mode whenever possible i.e., the BCAS listens to the replies of intruders to ground interrogations, but makes no interrogations of its own. In some situations, BCAS must augment the passive surveillance with its own active interrogations, in order to obtain accurate surveillance on intruders. In cases where the BCAS is not in view of any ground sensors, it receives surveillance only from its own active interrogations. This data is not suitable for issuing horizontal resolution advisories. The interface developed during this study was designed to operate correctly, regardless of the mode of surveillance being used by BCAS.

The Federal Aviation Administration (FAA) is also investigating the capabilities of a BCAS that operates only in the active surveillance mode.

This is referred to as the active BCAS. The active BCAS currently being studied has evolved from that described in References 4 and 5. Whether the FAA will permit one or both of these systems to be implemented has not yet been determined. Even though the interface developed in this study was not developed explicitly for the active BCAS, it can be used to provide the same level of interface capability between this version and ATARS as for the full-capability BCAS. However, since the active BCAS is limited to the use of vertical resolution, it may not be able to use the coordination information in multiaircraft situations as effectively as the full-capability BCAS. By using the same interface logic with the active BCAS as with the full-capability BCAS, a consistent operation would be ensured in the case where both versions of BCAS were implemented operationally.

C-1.2 Requirements of the ATARS-BCAS Interface

A study of design alternatives for an ATARS-BCAS interface was conducted as a first step in the development of the interface. This study revealed a number of problems in creating an effective mechanism for dynamically assigning separation assurance responsibilities. Three key technical problems to be considered were: 1) providing protection against pop-up intruders (those which enter surveillance coverage from beneath the coverage floor and cause an immediate collision threat), 2) providing coherent resolution of multiaircraft encounters, and 3) providing continuous and coordinated resolution when conflicts arise as aircraft are crossing the boundaries between areas of ATARS and BCAS responsibility. Unfortunately, neither the frequency nor the importance of these problems could be quantified in operational terms.

It was found that each problem could be solved by augmenting the interface design with a new feature, involving a certain amount of additional complexity in the logic or in the required communications. In reviewing possible design

alternatives, the Aircraft Separation Assurance Task Force made certain decisions as to the desirability of various interface characteristics. The design presented in this appendix is responsive to the requirements that the Task Force felt were necessary. These requirements are discussed below.

The first requirement is that ATARS should be the system responsible for providing separation assurance service, wherever such service can be provided by ATARS. This requirement would be fairly easy to achieve, by simply having the BCAS equipment inhibit generation of resolution advisories whenever the BCAS-equipped aircraft is receiving service from ATARS. However, another requirement that was imposed upon the ATARS-BCAS interface was that BCAS, when within ATARS coverage, should provide protection against "pop-up" intruders not visible to ATARS. This situation occurs, for example, when an aircraft beneath the floor of coverage of the Discrete Address Beacon System (DABS) is in danger of colliding with a BCAS-equipped aircraft within DABS coverage, but operating close to the coverage floor. It is further required that BCAS-generated resolution advisories against pop-up intruders be transmitted to the ATARS ground system so that they can be used as constraints in any further actions that ATARS might take in this conflict. Because of this requirement that BCAS protect against pop-up intruders, a simple interface, that causes BCAS advisories to be inhibited whenever the BCAS aircraft is within ATARS coverage, cannot be used.

Additional requirements of the interface relate to the logical consistency of the advisories issued to the aircraft. Duplication of advisories should be avoided. That is, ATARS and BCAS should not both issue advisories to a given aircraft to protect it against the same intruder. However, ATARS is permitted to issue an advisory to a particular aircraft to protect it against one intruder, while BCAS issues an advisory to protect it against another intruder. When this happens,

the resolution advisories issued to that aircraft by both ATARS and BCAS must be compatible. One must not issue a Climb while the other issues a Descend. Furthermore, all aircraft in a multiaircraft encounter should receive mutually consistent advisories, so that the hazard is not worsened by the advisories.

The advisories that result from this interface should have continuity. That is, once an advisory has been issued to protect an aircraft against a particular intruder, that advisory should not change because responsibility has been handed off from one system to another or because a new intruder has become involved in the conflict.

A further requirement of the interface is that it provide unambiguous coordination between the separation assurance system elements in the case of multiaircraft encounters. This requirement must be met for multiaircraft encounters involving all combinations of equipage and coverage. A single aircraft may be equipped with ATARS, with BCAS, or with only an altitude reporting DABS or Air Traffic Control Radar Beacon System (ATCRBS) transponder. The aircraft may be within or outside ATARS coverage and may be observed only by ATARS, or only by BCAS, or by both systems.

Two additional required properties of the interface are that the interface be resilient to transient communications losses and that minimum additional time delay in the pilot's receiving advisories be introduced due to coordination. For example, the coordination process must not fail because the DABS sensor has lost contact with an aircraft for one or two scans due to a fade. The requirement for minimizing the delay in displaying the advisories means that coordination cannot be permitted to take place over a period of several radar scans.

The interface should permit the BCAS equipment to acquire surveillance data within ATARS service areas, at the most complete level possible without creating unacceptable interference with the ATCRBS

and DABS surveillance systems. Even though the BCAS equipment will inhibit BCAS-generated advisories, a full capability BCAS will have tracks for all intruders so that immediate BCAS protection can be provided in event of failure of the DABS sensor.

One last requirement is that the interface provide a mechanism for the coordination of traffic advisory messages as well as for resolution advisory messages. ATABS and BCAS should not be permitted to display to a particular aircraft duplicate traffic advisory messages regarding the same intruder.

C-1.3 Assumptions

Two assumptions related to avionics equipage were made in this study. One is that an aircraft equipped with BCAS will also be equipped with a DABS transponder. Whether the DABS transponder is a separate device or the DABS capability is incorporated within the BCAS equipment is immaterial. The other assumption is that an aircraft equipped with a DABS transponder does not necessarily have an ATABS display or BCAS capability.

Another assumption is that ATARS and BCAS multiaircraft collision avoidance logic exists, or can be created. No multiaircraft resolution logic was developed during this study. It was found that it was not necessary to know what the multiaircraft logic was in order to develop the interface. The interface logic provides for communication of all necessary conflict resolution information between aircraft or between aircraft and the ATARS system on the ground.

C-1.4 Outline of the Remaining Text

In the following section, the interface is described in terms of actions that occur when ATARS and/or BCAS detects a conflict between aircraft at the boundary between the ATARS and BCAS service zones. It will be shown how rapid

and unambiguous designation of system responsibility can be achieved through communication of conflict information from aircraft to aircraft and from aircraft to the ground. It will also be demonstrated that multiaircraft encounters can be coordinated by successive pairwise applications of the coordination logic. The information contained in ground-to-air, air-to-air and air-to-ground coordination messages will be described. The logic and the sets of messages represent a single capability which provides for 1) ATARS resolution of conflicts which are wholly within ATARS coverage, 2) a coherent resolution of conflicts at the boundary of ATARS coverage, and 3) a coordination mechanism for use in BCAS-to-BCAS encounters which occur outside of ATARS coverage.

Next, the computer decision logic and the contents of messages needed to realize the interface are presented and discussed in detail. A set of conflict information, which is the focus of all system responsibility transactions, is described as well as a function which oversees and controls its activity. Finally, the ramifications of adopting this interface upon current designs are identified.

C-1.5 Status of the Interface Logic

Although every attempt was made to verify correctness of the logic as it was developed, time was not available to analyze its operation in every conceivable situation. There is a very large number of possible combinations of equipage, ATARS coverage at the beginning of the conflict, coverage transitions during the conflict, sequence of coordination messages being sent, signal fades, etc., even for a three aircraft encounter Since exhaustive testing was not performed, the material presented in this appendix should be considered a first design and not a final verified algorithm specification.

C-2. CHARACTERISTICS OF THE INTERFACE

In this section, the basic mechanisms of the interface's operation will be described, both in general and using specific examples. The nature of a collection of conflict information, central to the functioning of the interface, will also be discussed. Presentation of detailed decision logic, which utilizes this information and initiates and responds to special coordination messages, is deferred to the following section.

C-2.1 ATARS and BCAS Service Zones

The boundaries that determine where ATARS and BCAS service are provided are shown in Figure C-2-1. The first boundary that is discussed is the ATARS service zone boundary. At the DABS coverage floor, ATARS service is not deliberately terminated. ATARS provides service for all aircraft that are visible to it. However, a service zone boundary is maintained by ATARS in range. Aircraft are not tracked beyond this range boundary. The location of this range boundary is determined by the multisite configuration or by the maximum service range of ATARS discussed in Appendix A. Whenever an aircraft is within the ATARS service zone of a particular site, that site will uplink its site ID each scan, indicating that it is providing ATARS service to that aircraft (see Section C-2.2).

ATARS maintains a second boundary in its memory which determines when a BCAS aircraft is permitted to make routine active interrogations in order to provide protection against threats outside the ATARS service zone. The height of the floor of this boundary is established sufficiently above the DABS coverage floor so that BCAS would be able to provide protection against any aircraft climbing at reasonable rates from below the coverage floor. Likewise, the position of the BCAS active interrogation boundary in range is established so that BCAS could protect against threats with reasonable speeds approaching from beyond the ATARS service zone range boundary. If

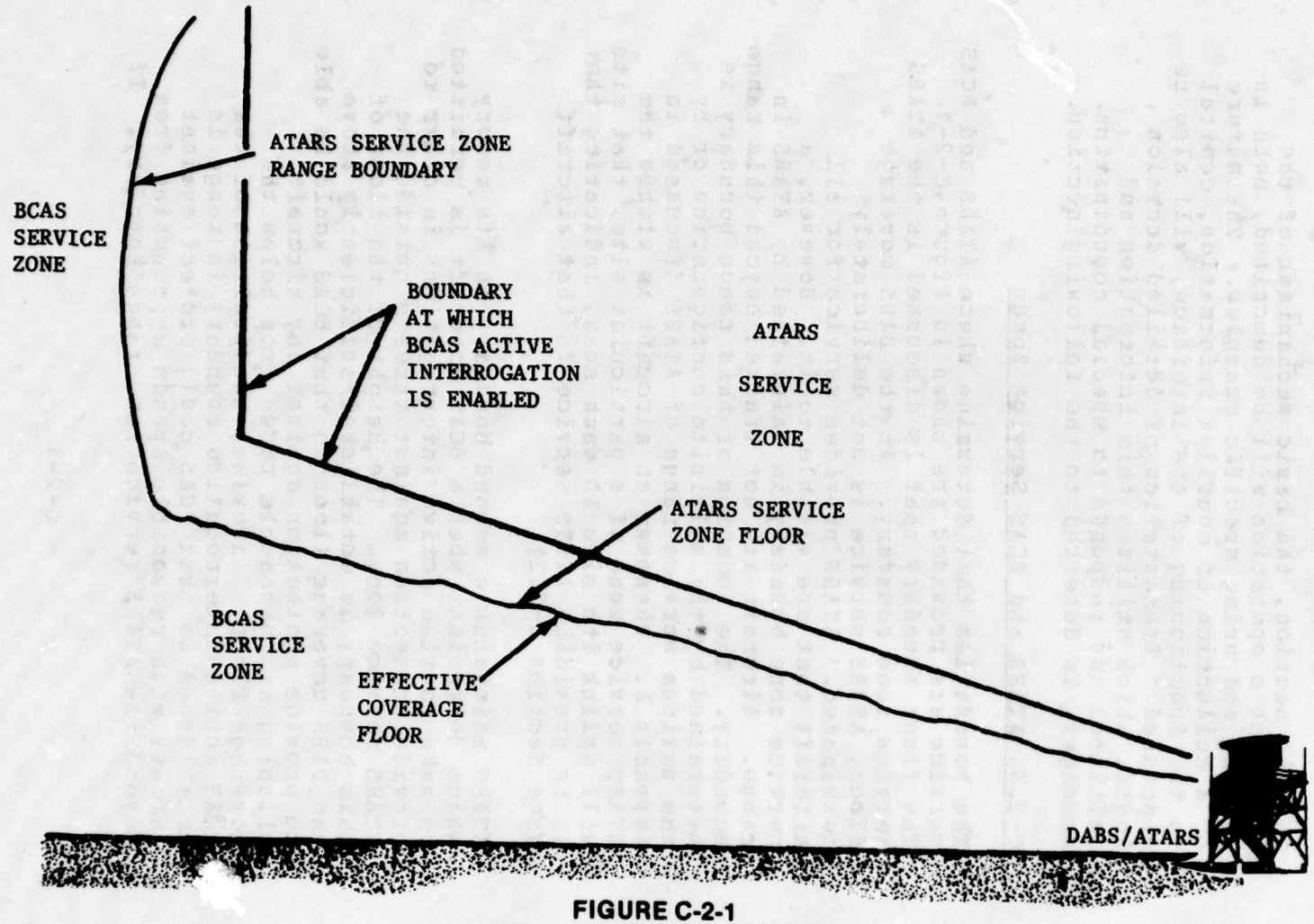


FIGURE C-2-1
SERVICE ZONE DEFINITION

the ATARS service zone range boundary is at a boundary shared with an adjacent site, the BCAS will not be permitted to make routine active interrogations in this area.

When a BCAS or a DABS-equipped aircraft is inside the boundary for BCAS interrogation in the active mode, the ATARS site will uplink a lockout bit in every surveillance interrogation. This bit will cause the BCAS to cease making routine active interrogations. It will also cause either a BCAS or a DABS-equipped aircraft to cease making routine squitter transmissions. A squitter transmission is a message sent out periodically and spontaneously by the DABS trnasponder without being elicited by an interrogation. It is used to permit BCAS to acquire new intruders in the active mode. If the DABS transponder fails tc receive interrogations from the ground with the lockout bit set, it will automatically unlock after a specified period of time and will start issuing squitter transmissions. In the same way, a BCAS aircraft will automatically unlock and will begin making active interrogations.

The BCAS active interrogation lockout applies to routine active interrogations. It does not prohibit the full capability BCAS from making active interrogations to resolve certain ambiguous geometries that arise in the passive modes. If interference to normal ground ATCRBS or DABS surveillance were to result from routine BCAS active interrogations, then BCAS would be locked out to active interrogations at boundaries that were as close to the ATARS service zone boundaries as possible. However, where interference would not be a problem, the boundaries could be set so that active interrogation would be permitted in more airspace. This would permit an active BCAS to maintain tracks, even though ATARS had separation assurance responsibility, so that the BCAS could provide protection immediately if the DABS sensor were to fail.

The active interrogation lockout boundary also becomes a boundary at which the BCAS equipment

ceases to conduct coordination interrogations. Inside this boundary, the BCAS equipment may track aircraft in the passive mode, but it will inhibit the display of BCAS resolution advisories, regardless of the conditions applying to a threat aircraft. All protection will be provided by ATARS. Outside this boundary, the BCAS uses coordination interrogations to determine the conditions affecting a threat aircraft. Then either ATARS or BCAS accepts responsibility depending upon whether the threat is seen by ATARS or is a pop-up threat.

C-2.2 The Conflict Indicator Register (CIR)

It is convenient at this point to introduce the set of information which is the central repository of responsibility information. It is called the Conflict Indicator Register (CIR). A CIR is located in every aircraft containing an ATARS or BCAS display. An aircraft equipped only with an ATCRBS transponder will not have a CIR. The CIR is not a special piece of hardware but is embedded within the logic associated with the ATARS or BCAS display. The meanings of the proposed CIR bits and bit fields are now addressed. See Figure C-2-2 for a depiction of the CIR.

One ATARS service bit (the A bit) and one site ID field (four bits) are present in the CIR at all times. The site ID field is used in transmitting ATARS multisite information via the transponder (see Appendix G) and is used only indirectly in the ATARS-BCAS interface actions. Each ATARS ground site is assigned one of four site ID's. Each bit in the site ID field refers to one of these site ID's. Every scan, for as long as an aircraft is within the ATARS service zone of a particular site, that site will uplink its site ID in the surveillance interrogation. The CIR will set the corresponding bit in the site ID field to one and will reset a timer for that site ID to zero. The CIR will periodically observe the timer for each site ID. If the timer for one particular ID has reached a certain threshold value, the CIR will reset the corresponding bit in the site ID

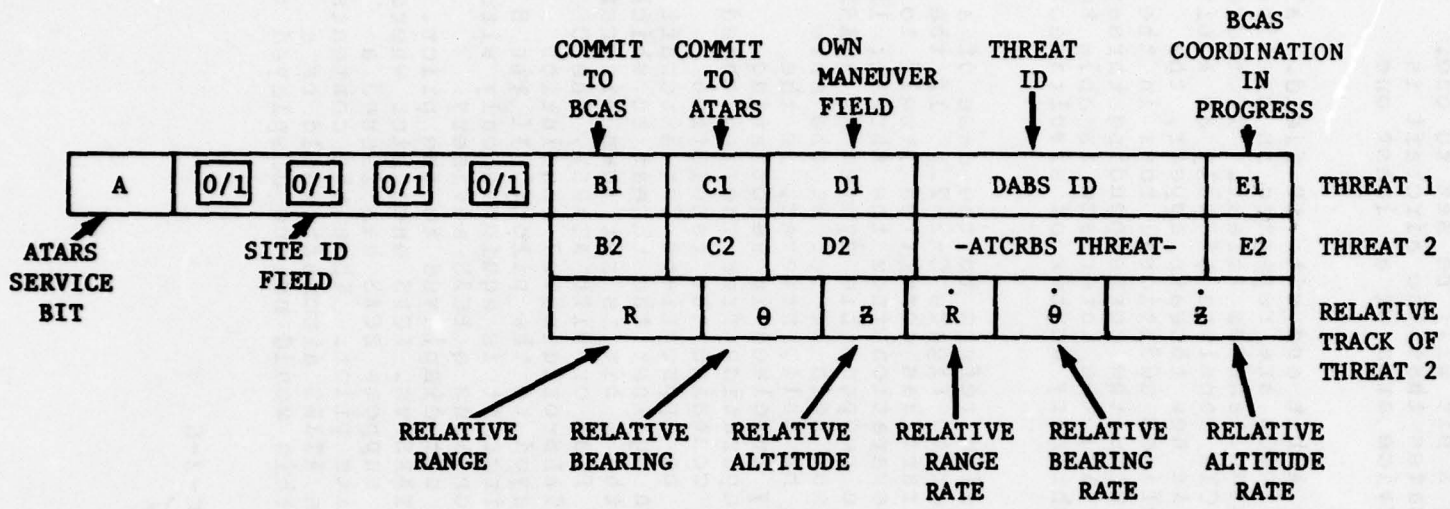


FIGURE C-2-2
THE CONFLICT INDICATOR REGISTER (CIR)

field to zero. If several sites simultaneously have the aircraft in their ATARS service areas, several site ID bits may be set in the site ID field. Every time the transponder receives a surveillance interrogation the site ID field will be updated appropriately. If any bit in the site ID field is one, the A bit will be set to one. The A bit thus indicates that the aircraft is within the ATARS service area of at least one ATARS site.

The CIR has only one A bit and site ID field. All other bits and bit fields are repeated in distinct rows, one for each simultaneous threat. If there are no threats, the CIR consists of only an A bit and site ID field. As new threats appear, the airborne computer defines additional rows in the CIR and releases them as the corresponding threats disappear. In this way, the interface is able to coordinate for an arbitrary number of simultaneous threats.

The following discussion refers to the case of a single threat. (Refer to Figure C-2-2.) If the B bit is set, the aircraft has committed itself to BCAS for providing separation from the threat; if the C bit is set, the responsible system is ATARS. The B and C bits cannot both be set at the same time. They may both be null, however, if the aircraft is currently involved in negotiating responsibility for separation from the indicated threat. The D field contains the resolution maneuver which would be appropriate for aircraft to provide separation against the threat to which the row refers. If the C bit is set (own aircraft may be equipped with BCAS or with ATARS), the D field contains the ATARS-originated resolution advisory being displayed to the pilot. If the B bit is set and own aircraft is equipped only with ATARS, the D field contains a BCAS advisory complement, which is not displayed to the pilot. For example, in an ATARS vs. BCAS encounter where BCAS is responsible, suppose BCAS has issued a descend advisory to its pilot. Then the contents of the D field in the ATARS aircraft would be a climb advisory, and this would not be displayed to

its pilot. The contents of the D fields are used as constraints in the selection of advisories when secondary, tertiary, etc., conflicts materialize.

The D field is composed of ten bits. The coding of these ten bits is indicated in Table C-2-1. It is necessary that this coding be able to indicate the presence of any horizontal maneuver concurrently with the presence of any vertical maneuver, because, in a few special situations, the current ATARS logic can simultaneously issue both horizontal and vertical advisories to protect against a single threat. The interface logic provides for the coordination of vertical speed limit (VSL) advisories as well as for positive and negative advisories. Individual bits within the D field make this possible. Three spare bits have been provided within the D field.

The ID field of the CIR contains information related to the identity of the threat aircraft. If the threat is DABS equipped, the ID field contains the threat's twenty-four bit DABS ID. If the threat is ATCRBS-equipped the ID field contains the ATCRBS Mode-A code being transmitted by the threat. Whenever one row in the CIR pertains to an ATCRBS aircraft, it is understood that the next CIR row contains the threat's track relative to own. This relative track (relative range, relative bearing, relative altitude, and their rates) and Mode-A code are used to identify the ATCRBS-equipped threat to other computers. Associated with the CIR row for such a threat is also a local ID, by which the ATARS-ECAS interface and the BCAS logic on the same aircraft identify it when communicating with each other.

The active BCAS or the full capability BCAS in its active mode may not make Mode-A interrogations of threat aircraft. If this is the case, the threat ID field of the CIR will be filled with all zeros. The Mode-A code will not then be used in identifying ATCRBS threats between different computers. For BCAS operating in an active mode it is also possible that bearing information will not be available or will be of low accuracy. In

TABLE C-2-1

CODING OF THE CIR D FIELD

BIT#		
1	0 = No horizontal command	1 = Horizontal command
2	0 = Horizontal is positive	1 = Horizontal is negative
3	0 = Sense is turn left or don't turn right	1 = Sense is turn right or don't turn left
4	0 = No vertical command	1 = Vertical command
5	0 = Vertical is positive	1 = Vertical is negative or or VSL according to bit 6
6	0 = Negative	1 = VSL
7	0 = Sense is climb or don't descend	1 = Sense is descend or don't climb
8	Spare	
9	Spare	
10	Spare	

this case, bearing information will not be used in the identification process.

Finally, the E bit is set when BCAS-to-BCAS coordination, a process to be described later in this section, is in progress.

C-2.3 Example Conflict Scenarios

Rather than describing each part of the coordination process in general, several specific conflict scenarios (see Figure C-2-3) will be presented. In Figure C-2-3, an X marks the position of an aircraft when the hazard materializes. The ATARS and BCAS service zones are configured as in Figure C-2-1. Assume that all aircraft are outside the active interrogation inhibit boundary.

Consider Scenario A. Both aircraft are within the ATARS service zone, and consequently, their A bits are both set. When BCAS on aircraft 1 detects a hazard, it locks its CIR, assigns a row to the ID of aircraft 2, sets the E bit in that row, and fills the D field of that row with a provisional BCAS advisory. Next, it immediately transmits a special coordination interrogation, addressed to aircraft 2. The coordination interrogation contains the ID of aircraft 1, an indication that aircraft 1's A bit is set, and the complement of the provisional BCAS advisory stored in its D field. When aircraft 2 receives the coordination interrogation, it locks its CIR (if it is not busy), and then transmits a reply which contains everything in its CIR except its site ID field and F bits. If its CIR was busy when the coordination interrogation was received, aircraft 2 replies, in effect, CIR busy; try again. Aircraft 1 would retransmit the same coordination interrogation until it had received a reply or until a specified period of time had elapsed. After replying, aircraft 2 checks its CIR to see if its A bit is currently set. It is, and the BCAS advisory complement is rejected. When BCAS on aircraft 1 receives the reply, it recognizes that aircraft 2 is being given ATARS service, since aircraft 2's A

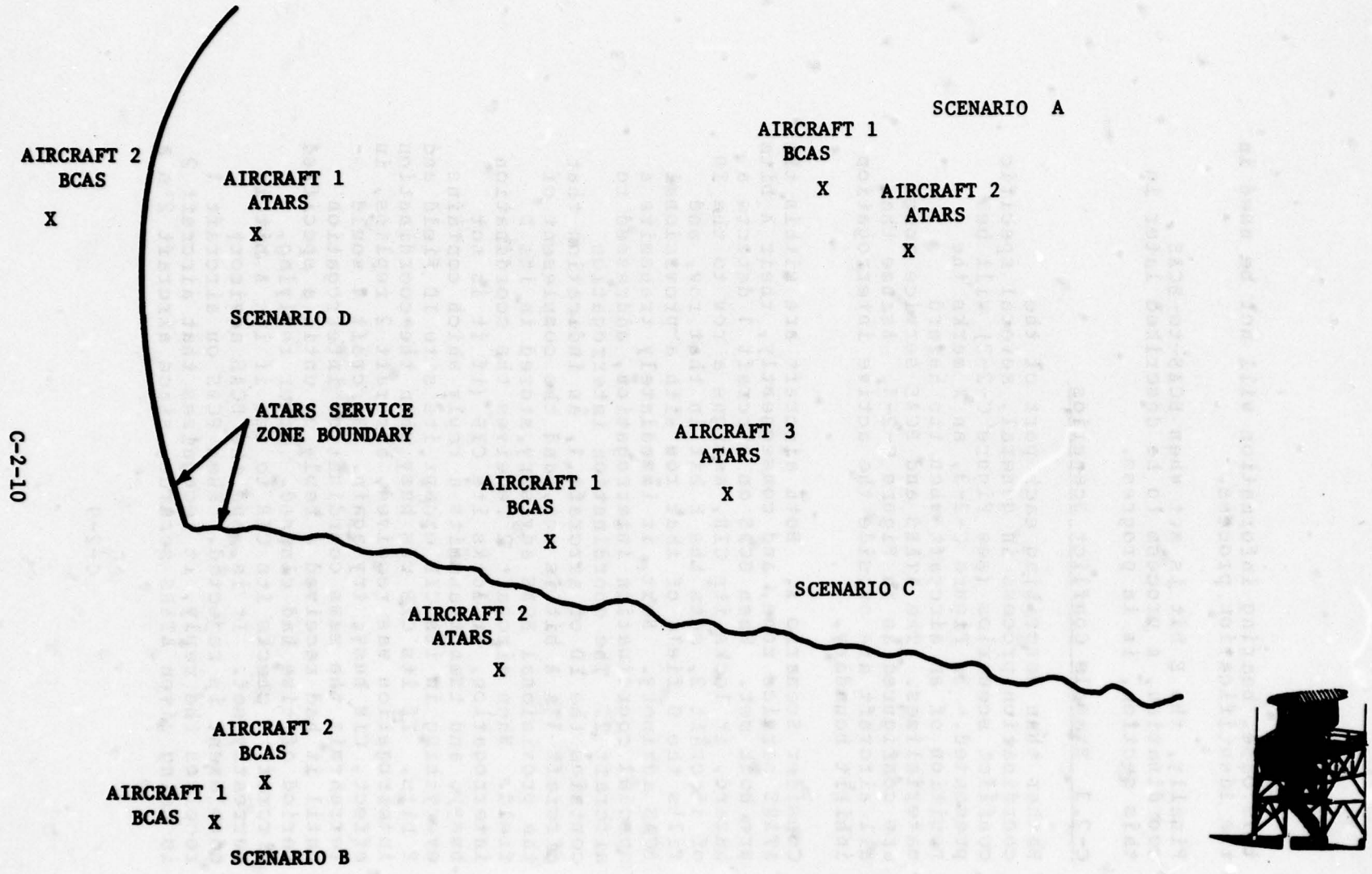


FIGURE C-2-3
EXAMPLE CONFLICTS

bit is set. Upon checking own CIR, BCAS finds that aircraft 1 is itself also being given ATARS service (since own A bit is set). BCAS then unlocks its CIR and surrenders the conflict to ATARS. In this way, BCAS is made to self-suppress when both own and threat are within ATARS protection.

Next consider Scenario B. Suppose BCAS on aircraft 1 is first to detect a hazard. As in scenario A, BCAS locks own CIR, sets up a row for aircraft 2, and sends a coordination interrogation to aircraft 2. Aircraft 2 locks its CIR, reads out its contents into the coordination reply, and examines the information sent in the coordination interrogation. That information identifies the sender as aircraft 1, and indicates that aircraft 1's A bit is not set. Upon checking own CIR, BCAS on aircraft 2 finds no row assigned to the ID of aircraft 1. It then establishes one, and sets the B bit committing to BCAS (because there are not two A bits set). When BCAS on aircraft 1 receives the coordination reply, it sees that aircraft 2's CIR contained no row assigned to aircraft 1, and then sets own B bit for aircraft 2, displays the BCAS advisory to its pilot, and unlocks the CIR. Thus, when both aircraft are outside the ATARS service zone, BCAS resolves the conflict.

Scenario C involves the coverage floor boundary of the ATARS service zone, as well as a third aircraft, so the full capability of the interface can be illustrated. According to the placement of the aircraft, it can be deduced that the A bits of aircraft 1 and 3 are set, while that of aircraft 2 is not set. Suppose the first conflict to materialize is aircraft 1 vs. aircraft 2. The air-to-air coordination informs BCAS on aircraft 1 that aircraft 2 is outside ATARS service, so BCAS sets own B bit corresponding to aircraft 2, and displays the associated advisory (stored in the D field of that same row) to its pilot. The next time ATARS interrogates aircraft 1, the entire contents of its CIR (except for the E bits) are downlinked. Upon receiving this information, ATARS sets up a conflict table for the aircraft 1

- aircraft 2 conflict, including the ID of aircraft 2 and the BCAS advisory being displayed to the pilot of aircraft 1. The conflict table also specifically indicates that ECAS is responsible for resolving that conflict.

Next, aircraft 3 comes into conflict with aircraft 1. The air-to-air coordination informs BCAS on aircraft 1 that both own and threat are within the ATARS service zone, so it ceases further BCAS activity and waits for ATARS to resolve the conflict. When ATARS detects the aircraft 1 - aircraft 3 conflict, it selects a set of advisories which is compatible with aircraft 1's BCAS advisory, which it finds from referencing the existing conflict table. ATARS then uplinks the advisory to aircraft 1, along with the ID of aircraft 3. Upon receiving the ATARS message, aircraft 1 locks own CIR, compares the message with own CIR, and finds that the row for aircraft 3 has not had its P bit set. It also finds that the ATARS advisory does not conflict with any other pre-existing advisory. If an incompatibility had been detected, the ATARS advisory would be rejected by aircraft 1. ATARS would then be forced to wait one more scan, during which it would reselect, if possible, an advisory for aircraft 1 which was compatible with the BCAS advisory and with the ATARS advisory accepted by aircraft 3. If an advisory cannot be found for aircraft 1 that is compatible with the BCAS advisory for aircraft 1 and the ATARS advisory accepted by aircraft 3, ATARS will reselect the entire set of advisories for the aircraft 1 - aircraft 3 conflict. This may mean that the advisory in aircraft 3 has changed. This particular situation represents the only known case in which the ATARS-BCAS interface has failed to meet all of the design requirements presented in Section C-1.2.

In the normal sequence of events in which the ATARS advisory is not rejected, aircraft 1 then sets the C bit in the CIR row associated with aircraft 3, stores the ATARS advisory in that row's D field, displays the ATARS advisory to its

pilot and unlocks own CIR. ATARS, of course, uplinks an advisory to aircraft 3, which sets up the appropriate CIR fields, etc. Thus, it can be seen that compatibility of advisories is assured by matching the coordination message information with the contents of the CIR. It is also apparent that the pop-up intruder is handled appropriately.

Suppose the first conflict to materialize had been aircraft 1 vs. aircraft 3. Then the first row in aircraft 1's CIR would have the C bit set, and an ATARS advisory in the D field. When aircraft 2 comes into conflict with aircraft 1, BCAS on aircraft 1 is able to select an evasive maneuver compatible with the ATARS advisory already being displayed (if such selection is possible based on the BCAS operating mode).

One should bear in mind that the CIR controller is all the while granting access to own BCAS logic, air-to-air coordination message processing, and ATARS message processing, one at a time. If the CIR is busy when the aircraft receives an interrogation from the ground, the aircraft replies with a CIR Busy message. The ground system will attempt repeated interrogations while the aircraft is still within the DABS antenna's main beam. More than ten opportunities for downlinking are normally available in one DABS scan, so the CIR can be read by the ground on any given scan with high probability.

In Scenario D, aircraft 2 does not have the ATARS service bit set. When the BCAS on aircraft 2 senses a conflict with aircraft 1, the air-to-air coordination gives responsibility to BCAS. ATARS will become aware of the BCAS conflict through downlinking of the CIR from aircraft 1. If aircraft 2 crosses the service zone boundary while the resolution of the conflict is in progress, ATARS avoids setting the site ID bit on the uplink until the conflict is over and aircraft 2 is reporting a null CIR.

Some additional features of the interface can be illustrated using Figure C-2-4. Assume again that

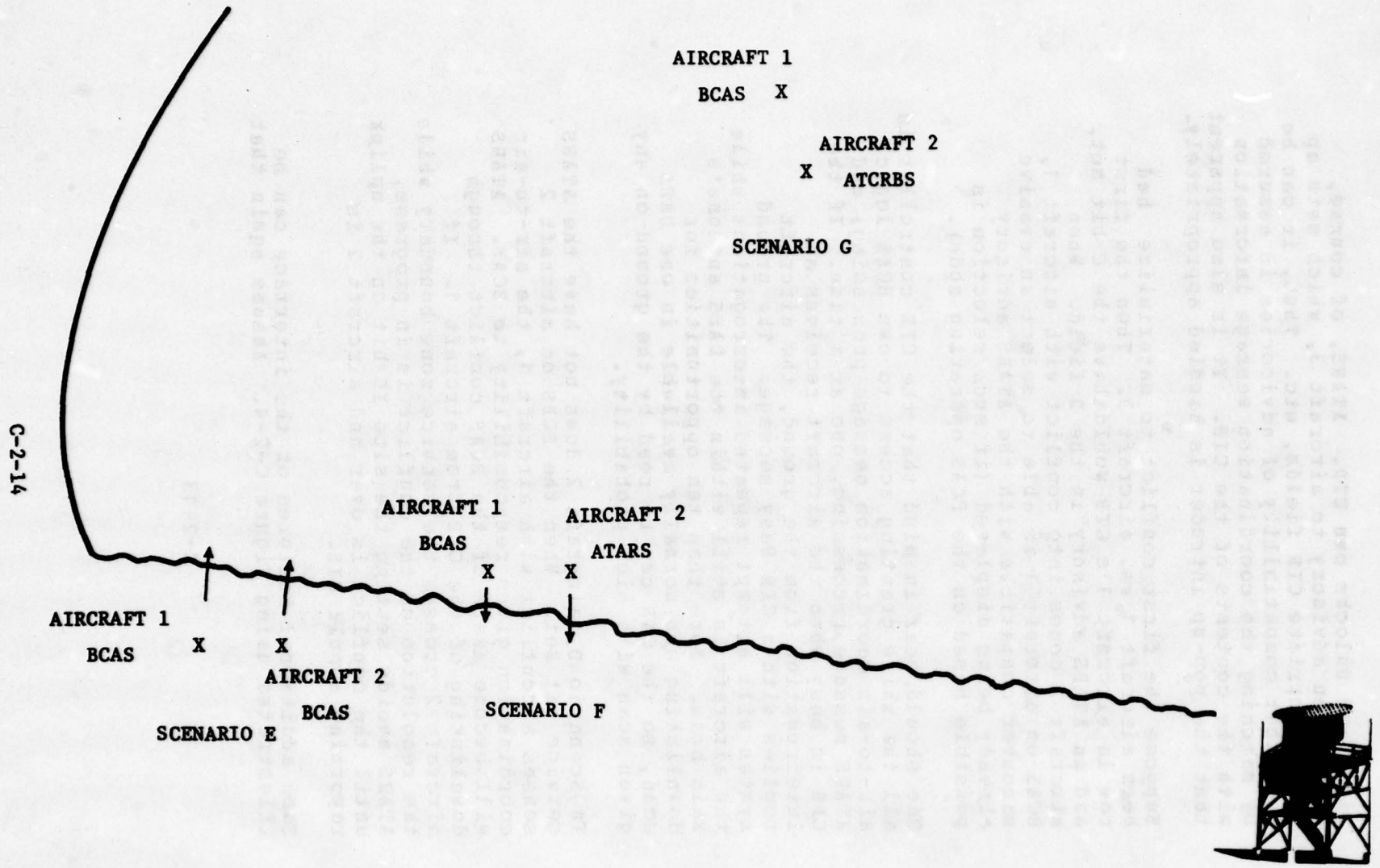


FIGURE C-2-4
ADDITIONAL EXAMPLE CONFLICTS

all aircraft are outside the active interrogation inhibit boundary. In Scenario E a conflict between two BCAS-equipped aircraft materializes when both aircraft are beneath the DABS coverage floor. Air-to-air coordination establishes BCAS as the responsible system. Then, as indicated by the arrows, both aircraft become visible to ATARS while the conflict is still in progress. On each interrogation from the ground, both aircraft would be downlinking the contents of their CIR's. ATARS sets up a conflict table for this pair, indicating BCAS as the responsible system, and does not uplink advisories even though the conflict is wholly within the ATARS service zone. From this type of action, one is prompted to refer to the boundary between the ATARS and BCAS service zones as a soft boundary. It can also be noted that if the boundary involved in this scenario were the range boundary, the same events would occur.

The reverse of this conflict is depicted in Scenario F. Here, a conflict between a BCAS and an ATARS aircraft materializes within the ATARS service zone, so ATARS is the responsible system. Even though BCAS is inhibited from displaying advisories, it is still free to periodically issue coordination interrogations to the threat aircraft, as long as it perceives a hazard. As the aircraft drop out of DABS coverage in the middle of resolving the conflict, the air-to-air coordination messages serve to update the timeout for the advisory existing on the display of the ATARS aircraft. Therefore, the ATARS-originated advisory remains displayed in the ATARS aircraft for as long as BCAS believes a collision threat exists. It is seen from this example that the boundary between the ATARS and BCAS service zones is soft in both directions. If the boundary in this scenario were the range boundary instead of the coverage floor boundary, the same effects would be observed.

Finally, in Scenario G, a BCAS-equipped aircraft comes into conflict with an ATCRBS-equipped aircraft. Since aircraft 2 does not have a CIR, it is not involved in the negotiation process.

Since it has no collision avoidance display, the only aircraft to receive resolution advisories is aircraft 1. Since aircraft 1 is outside the active interrogation inhibit boundary, it will conduct normal processing. Whether responsibility for this conflict falls to ATARS or BCAS depends on which system is first to set the B bit or C bit in the CIR of aircraft 1. The BCAS equipment will use a smaller lead time against ATCRBS threats than the lead time used by ATARS to ensure that ATARS will usually be the system accepting responsibility when it sees the ATCRBS threat. If the ATCRBS threat were below the DABS coverage floor, BCAS would accept responsibility. Thus, it is clear that the interface permits BCAS to protect against ATCRBS pop-up threats as well as BCAS and ATARS pop-up threats.

If, in all of the preceding example scenarios, a BCAS aircraft had been inside the active interrogation inhibit boundary, the BCAS aircraft would have inhibited BCAS resolution advisories automatically. It would not make coordination interrogations to determine the conditions in the threat aircraft. All resolution would be provided by ATARS in this case. Protection against pop-ups would not be required. Still, BCAS would be permitted to conduct passive surveillance and would be permitted to issue resolution advisories as soon after failure of a DABS sensor as the ATARS service bit becomes unlocked.

C-3. LOGICAL DESIGN OF THE INTERFACE

In this section, software structures and detailed decision logic for the ATARS-BCAS interface are presented and discussed. First, the high-level relationship between the BCAS collision avoidance logic and the ATARS-BCAS coordination function is described, including messages sent between the two systems. Then, the logical design of the CIR controller is presented, followed by decision logic flow charts for the actual coordination between ATARS and BCAS. Logic is included both for DABS transponders with ATARS capability but without BCAS, and for DABS-BCAS units.

C-3.1 Communications Between BCAS Collision Avoidance Logic and ATARS-BCAS Interface

The functions which track targets, detect conflicts, select (provisional) resolution advisories for evading them, and drive the cockpit display are described in the BCAS collision avoidance algorithms. These algorithms are presented as Appendix K to Volume III of Reference 3. For the sake of logical clarity, these functions have been kept distinct from the ATARS-BCAS interface. This subsection addresses the (intra-computer) messages sent between these two functions.

Communication between the BCAS collision avoidance algorithms and the ATARS-BCAS interface is always initiated by the BCAS algorithms. Three types of messages can be sent from the BCAS logic to the interface, and each has its own type of response. The first message type is sent when BCAS has detected a conflict, selected provisional resolution advisories for resolving it, and desires coordination for finalizing resolution advisories. The message sent to the interface consists of the threat ID, together with the provisional advisory set (e.g., Own Turn Right, Threat Turn Left), which is referred to as the variable NTENT in the BCAS collision avoidance algorithms. It is the task of the interface to test the OWN part of this provisional set of

advisories for compatibility with other advisories own aircraft might already be following, and to coordinate own's desire to resolve the conflict with the other computers involved.

Specifically, the interface determines whether or not own has already committed to ATARS for resolving the indicated conflict, and if not, performs air-to-air coordination with the threat to establish compatibility with the threat's intentions. Any level of incompatibility (between pre-existing own advisories, prior commitment by own or threat to ATARS, or pre-existing threat's intent) is resolved by the ATARS-BCAS interface, and the results are returned to the BCAS algorithms. If air-to-air coordination determines that the A bits of both own and threat are set, this fact is communicated to own BCAS. When BCAS desires to drop the advisory for an old threat (and only if the B bit is set for that threat), this message is sent to the interface one last time, with a null advisory indication (NTENT = 0). The interface logic will recognize this as an advisory deletion, and will delete the corresponding row(s) from the CIR.

The second type of message sent by the BCAS algorithms is a request for own A bit (this information is used to determine whether ATARS or BCAS should display traffic advisories) and the corresponding reply is own A bit. The third message type is a track update for an ATCRBS threat, against which separation is to be provided by BCAS. Since this type of threat is identified to other computers by its position and velocity relative to own, it is necessary to update this identification whenever own tracker estimates are updated. To facilitate correlation of the updated track with the old one already in the CIR, a local threat ID is included in this message. Since no use is made by BCAS of the knowledge that the track in the CIR has been updated, no reply is sent.

The intra-computer message set is summarized in Table C-3-1.

TABLE C-3-1

INTRA-COMPUTER MESSAGE SET FOR COMMUNICATION BETWEEN
BCAS ALGORITHMS AND THE ATARS-BCAS INTERFACE

MESSAGE SENT FROM BCAS ALGORITHMS	REPLY SENT FROM ATARS-BCAS INTERFACE
1. THREAT ID + PROVISIONAL ADVISORY	1. THREAT ID + { OWN 'B' AND 'C' BITS, OR BOTH 'A' BITS SET, OR COMMITTED ADVISORY IF OWN 'B' BIT SET
2. OWN 'A' BIT REQUEST	2. OWN 'A' BIT
3. ATCRBS THREAT TRACK UPDATE: LOCAL ID + RELATIVE COORDINATES	3. NO REPLY

* ADVISORY SET IS NULL IF BCAS IS DROPPING AN OLD ADVISORY.

C-3.2 CIR Controller

The software mechanism which oversees the use of the CIR is referred to as the CIR Controller. The purpose of the CIR Controller is to permit only one function at a time (branch of logic, reply to air-to-air coordination interrogation, etc.) to be serviced by the CIR. In this way, it prevents scrambling of coordination actions due to time-interleaving of events. A function desiring access to the CIR causes a lock command to be sent to the CIR Controller, along with the ID of the threat with which that function is currently concerned. If the CIR is not busy, the CIR Controller grants access to the requesting function, and simultaneously locks out other functions from gaining access. When the function is finished using the CIR, an unlock command is sent to the CIR Controller, which then frees the CIR for access by other functions. If a function sends a lock command to the CIR Controller while the CIR is busy, the CIR Controller denies access by replying "CIR Busy" and a loop keeps sending lock commands from the requesting function until it gains access.

If the function desiring access to the CIR is servicing an interrogation received from another system (i.e., ATARS or another BCAS), the following actions occur. A partial decoding of the interrogation determines the nature of the sender. If the sender is BCAS and if the CIR is in the UNLOCKED state, its contents are read out directly into the coordination reply; the CIR in this case acts as a reply message buffer. If the CIR is in the LOCKED state, a "CIR Busy" indication is read directly into the reply. However, an exception occurs if the CIR is busy because own BCAS has made a coordination interrogation of another BCAS at the time a coordination interrogation is received from this same BCAS. In this case, the reply to the coordination interrogation depends upon which DABS ID has the higher order address. If the other BCAS has the higher order address, a priority interrupt of the logic using the CIR is performed,

the CIR is sent in a coordination reply, and the coordination interrogation is serviced. In the case when the CIR is free and available for readout into the reply, that readout action is simultaneous with locking the CIR. The CIR reply logic is explained further in the following subsection.

C-3.3 Detailed Coordination Logic

Logic which is to be executed upon receipt of an interrogation from another system is presented in Figure C-3-1. It must be performed by aircraft equipped with ATARS and by aircraft having full BCAS units. This logic is executed in parallel with the transmission of the CIR or the "CIR Busy" message. The interrogation is examined in order to decide whether the sender is ATARS or another BCAS. In the former case, the ATARS coordination logic, presented in Figure C-3-2, is executed. A picture of the CIR is included in this figure for easy reference.

Since the logic in Figure C-3-1 is executed simultaneously with the the transmission of the reply, the logic in Figure C-3-2 must first determine whether the CIR is being returned or a "CIR Busy" message is being returned. If the CIR was free at the moment the interrogation was received, its contents were downlinked to ATARS, and the CIR was simultaneously locked. This logic then has access to the CIR.

The message sent from ATARS is examined to determine if it contains any positive or negative resolution advisories. If it does not, the site ID bits in the uplink are observed and the site ID field in the CIR is updated. The A bit in the CIR is then updated. If the A bit is set, then the the current time is recorded as the variable LTABS ("last time 'A' bit set"). If the A bit is not set, and if 16 seconds (system parameter) have elapsed since the last time it was set, own A bit is reset. This timeout prevents the CIR's ATARS service bit from remaining set after the aircraft has passed out of DABS coverage. Since no ATARS

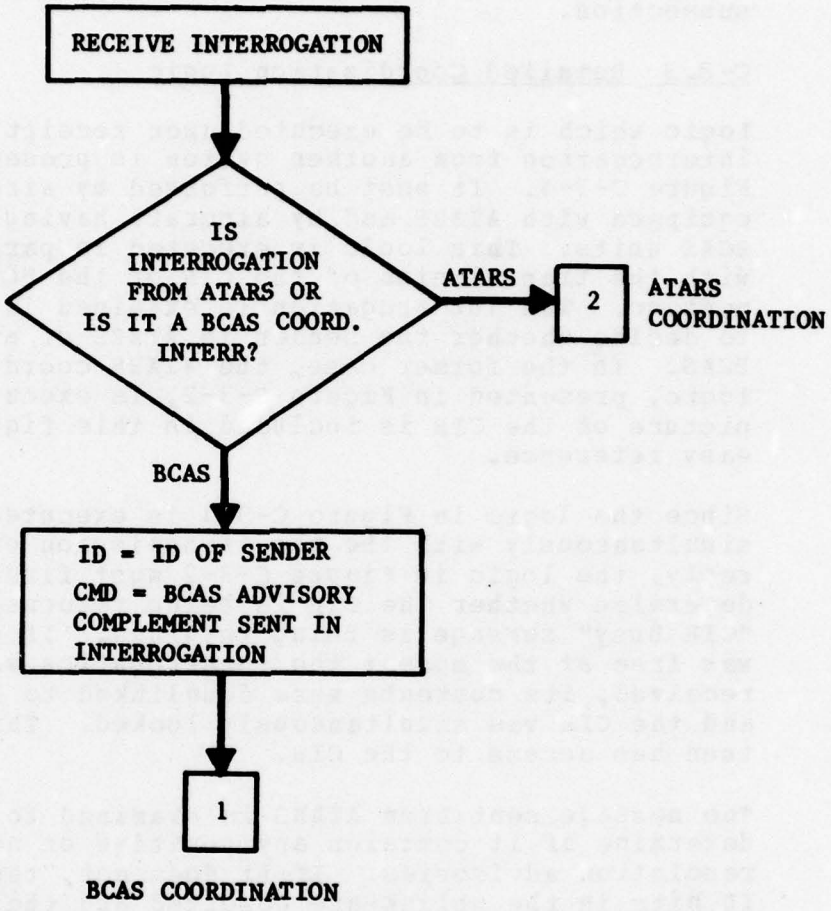


FIGURE C-3-1
LOGIC PERFORMED BY BCAS OR ATARS AVIONICS ON RECEIPT OF AN INTERROGATION FROM ANOTHER BCAS OR ATARS

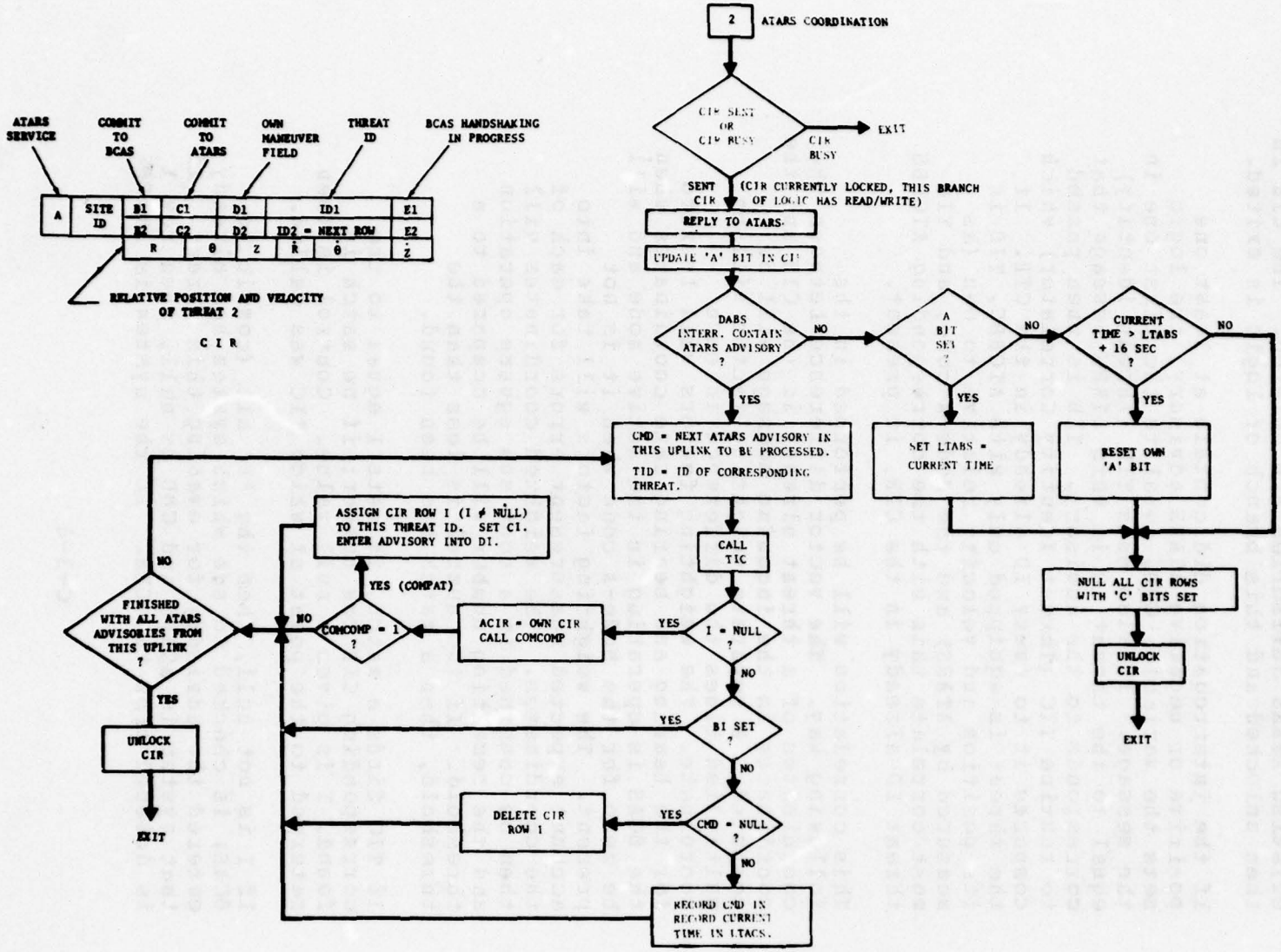


FIGURE C-3-2
ATARS COORDINATION LOGIC PERFORMED BY BCAS OR ATARS AVIONICS

advisories are present in this message, all existing ATARS advisories are deleted. The CIR is then unlocked and this branch of logic is exited.

If the interrogation did contain at least one positive or negative ATARS advisory, the logic sets the variable, CMD, equal to the first one in the message. It also sets TID (threat identity) equal to the threat ID in this ATARS message that corresponds to the advisory. TID is then passed to routine TIC (Threat Identity Correlator) which compares it to every ID already in the CIR. If the threat is equipped only with ATCRBS, TID is its position and velocity relative to own (as measured by ATARS) and the Mode-A code, and TIC must correlate this with the corresponding ATCRBS threat ID already in the CIR, if present.

This correlation will be performed in the following way. The vector difference between the coordinates of a threat already in the CIR and the coordinates in the incoming message will be computed. A separate weighting factor will be multiplied times the difference in each coordinate. The weighting factors will be zero for the bearing and bearing rate coordinates when the BCAS is operating in the active mode and will be zero for the Mode-A code when it is not present. The weighting factors will take into account expected measurement errors for each of the coordinates. The weighted coordinates will then be combined in a root sum square operation and the resulting number will be compared to a threshold. If the number is less than the threshold, then a match has been found.

If TIC finds a match, it sets I equal to the corresponding CIR row number; if no match is found, I is given a null value. Control is then returned to the point at which TIC was called.

If I is not null, then the 'B' bit (commit to BCAS) is checked to see which system has already entered the advisory for evading this threat. If that system is ATARS and CMD is null, then row I is deleted from the CIR. If the system is ATARS

and CMD is not null, then the resolution advisory for that threat from the uplink is copied into the D field in the CIR. The current time is recorded in the variable LTACS ("last time ATARS command set"). LTACS is used as a timeout which causes advisories to be automatically turned off after a specified time if the aircraft leaves the ATARS service zone through the DABS coverage floor.

If TIC returns a null value of I, then this is the first advisory received from any system for evading this particular threat. A check is performed to determine whether the ATARS advisory received on this uplink is compatible with all other advisories appearing in the CIR. If a new BCAS advisory (for evading some other threat) had appeared in the CIR after the previous downlink, ATARS would not have been able to use it as a constraint in selecting advisories. To check for compatibility, the ATARS advisory received on this uplink (CMD), together with an image of the CIR (ACIR), is passed to routine COMCOMP ("command compatibility"). This routine compares CMD with all D fields (own intents) already in the CIR. COMCOMP uses the compatibility matrix presented in Table C-3-2 to make this determination. If no incompatibility is detected, a row in the CIR is allocated to the indicated threat, CI is set (committing to ATARS for separation from this threat), and the ATARS advisory is written into the intent field D. If any other ATARS advisory received on this uplink remains, it is processed. If not, the CIR is unlocked and this branch of logic is exited.

If the logic presented in Figure C-3-1 determines that the interrogation was a BCAS coordination interrogation, ID is set equal to the DABS ID of the sender (included in that interrogation), and CMD is set equal to the BCAS advisory complement, also sent in the interrogation. The logic presented in Figure C-3-3 is then executed.

A check is first made to determine whether the DABS ID of the sender is of higher priority (is larger) than own DABS ID. If it is not, a reply

TABLE C-3-2

RESOLUTION ADVISORY COMPATIBILITY MATRIX

	TR	TL	CL	DES	DTR	DTL	DCL	DDES
TR	1	0	1	1	0	1	1	1
TL	0	1	1	1	1	0	1	1
CL	1	1	1	0	1	1	0	1
DES	1	1	0	1	1	1	1	0
DTR	0	1	1	1	1	1	1	1
DTL	1	0	1	1	1	1	1	1
DCL	1	1	0	1	1	1	1	1
DDES	1	1	1	0	1	1	1	1

1 = COMPATIBLE

0 = INCOMPATIBLE

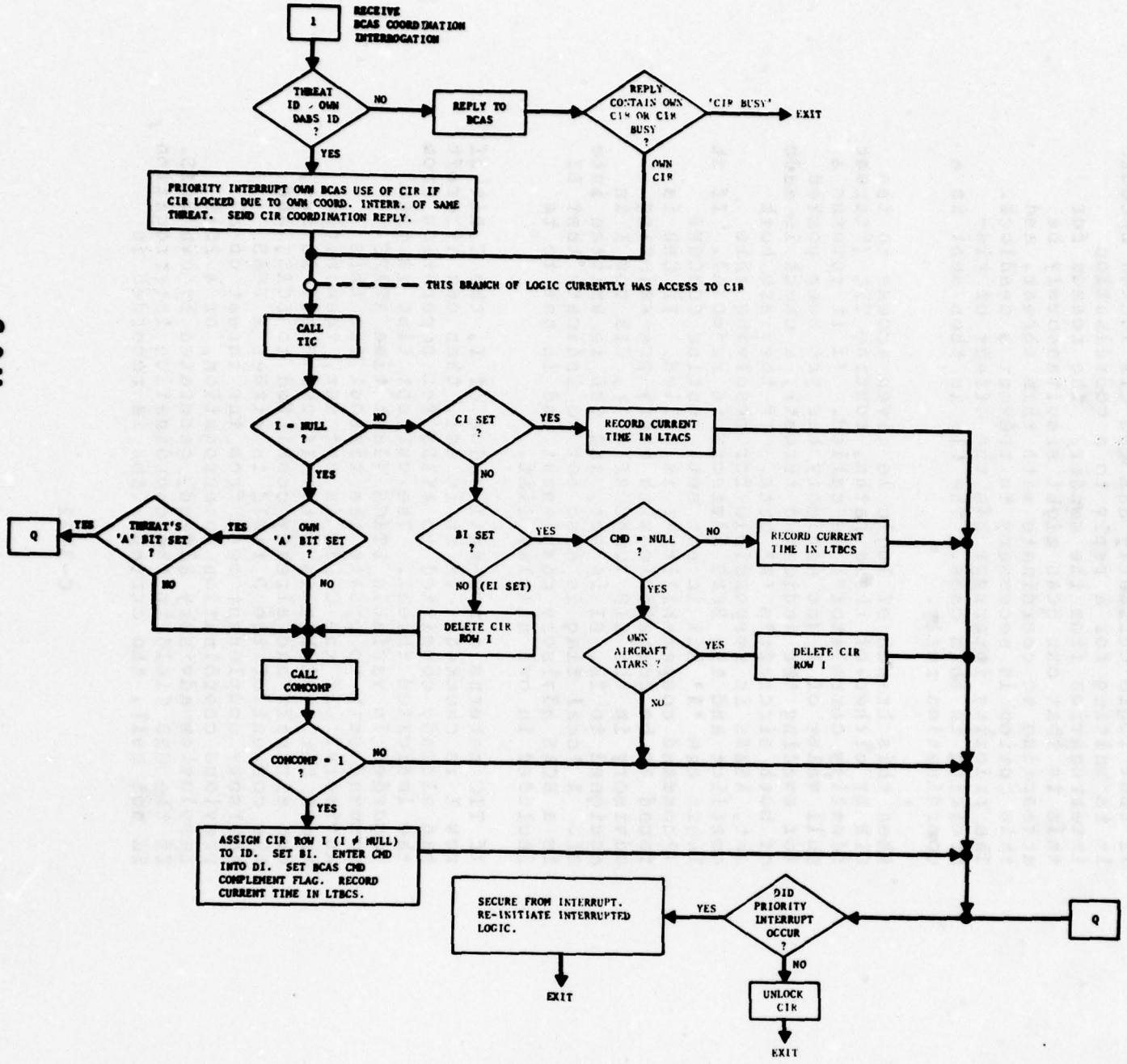


FIGURE C-3-3
BCAS COORDINATION LOGIC PERFORMED BY BCAS OR ATARS AVIONICS

is emitted containing ow CIR if it is not busy at the moment, or a CIR Busy message if it is busy. If the sender's ID is of higher priority than own ID, own BCAS logic's use of the CIR is interrupted if that logic currently has the CIR locked because it is waiting for a reply to a coordination interrogation from the sender. The reason for this is that own BCAS might simultaneously be attempting to coordinate with this threat, and this action is necessary to prevent a deadlock. The priority interrupt has the effect of tie-breaking in this case. The CIR is then sent in a coordination reply.

When this branch of logic is given access to the CIR by either of these paths, routine TIC ("threat identity correlator") is called. If it returns a null value of I (nc advisory has yet been posted for evading the indicated threat), a check is made of both aircraft's 'A' bits. If they are both set, ATARS is responsible for resolving this conflict and the BCAS advisory is rejected. If at least one 'A' bit is not set, routine COMCOMP ("command compatibility") is called. If CMD is found to be compatible with every pre-existing advisory in the CIR (COMCOMP = 1), CIR row I is assigned to ID, BI is set, and CMD is written into DI. A local flag is also set to indicate that DI is a BCAS advisory complement and is not to be included in own display list.

If TIC returns a non-null value of I, the C bit of row I is checked. If it is set, then own aircraft had already committed to ATARS for separation from the indicated threat. The current time is then recorded in variable LTACS (last time ATARS command set) to update the timeout for this advisory. If the C bit is not set, then either the B bit or E bit is set. If the B bit is set, own aircraft had already committed to BCAS, and the content of the D field is either a BCAS advisory complement sent from the threat on a previous coordination interrogation, or a BCAS resolution advisory already generated by own BCAS. If the CMD field in the coordination interrogation is not null, the current time is recorded in

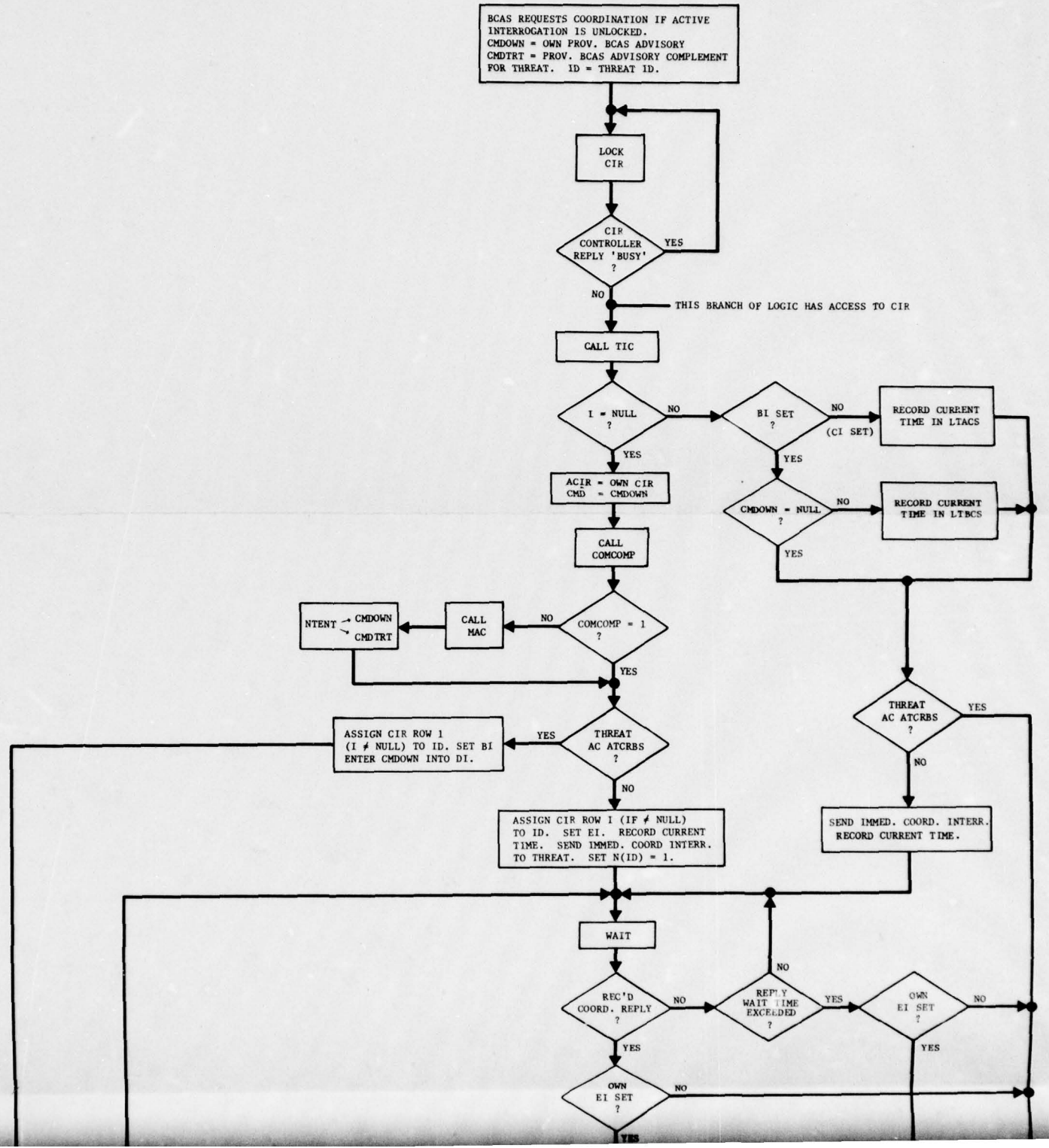
variable LTBCS ("last time BCAS command set"), to update that timeout. If the CMD field is null, then this coordination interrogation was made so that the CIR row for that threat would be deleted. However, the interface logic does not permit another BCAS to terminate the advisory against that BCAS if own is BCAS equipped. Only own's BCAS logic can cause advisories to begin or to terminate. The coordination interrogation with a null advisory is required to delete the CIR row from an aircraft equipped only with ATARS.

If neither the B bit nor the C bit is set, the only other way for a CIR row for this threat to have been allocated is for the E bit ("BCAS coordination in progress") to be set. This indicates that own BCAS had been involved in coordination and was interrupted by the present logic. In this case, the CIR row is deleted and CMD is sent to COMCOMP to determine compatibility, just as if TIC had returned a null value of I.

When this logic is completed, a check is made to determine if it had begun via a priority interrupt. If so, the interrupted logic is re-initiated (not continued at the interruption point) with access to the CIR being handed over to it. If no priority interrupt had occurred, the CIR is unlocked and this logic is exited.

Logic to be executed when own BCAS requests coordination of advisories is presented in Figure C-3-4. As discussed in Subsection C-3.1, the BCAS logic sends the threat ID and the set of provisional advisories (NTENT) to this logic. The first task is to separate NTENT into own provisional advisory (CMDOWN) and the complementary advisory for the threat (CMDTRT). A loop then sends lock requests to the CIR controller until access is granted.

The threat ID is then sent to routine TIC. If a pre-existing CIR row is found for this threat, the B bit is checked to determine which system is responsible. If that system is ATARS, the ATARS timeout variable LTACS ("last time ATARS command


BCAS REQUESTS COORDINATION IF ACTIVE INTERROGATION IS UNLOCKED.
CMDOWN = OWN PROV. BCAS ADVISORY
CMDTRT = PROV. BCAS ADVISORY COMPLEMENT FOR THREAT. ID = THREAT ID.
LOCK CIR
CIR CONTROLLER REPLY 'BUSY' ?
YES
NO
THIS BRANCH OF LOGIC HAS ACCESS TO CIR
CALL TIC
I = NULL ?
NO
BI SET ?
NO
(CI SET)
RECORD CURRENT TIME IN LTACS
YES
YES
ACIR = OWN CIR
CMD = CMDOWN
CMDOWN = NULL ?
NO
RECORD CURRENT TIME IN LTBCS
YES
CALL COMCOMP
COMCOMP = 1 ?
NO
CALL MAC
NTENT → CMDOWN
CMDTRT
YES
THREAT AC ATCRBS ?
YES
ASSIGN CIR ROW 1
(I ≠ NULL) TO ID. SET BI
ENTER CMDOWN INTO DI.
NO
THREAT AC ATCRBS ?
YES
NO
ASSIGN CIR ROW I (IF ≠ NULL)
TO ID. SET EI. RECORD CURRENT
TIME. SEND IMMED. COORD INTERR.
TO THREAT. SET N(ID) = 1.
SEND IMMED. COORD. INTERR.
RECORD CURRENT TIME.
WAIT
REC'D COORD. REPLY ?
NO
REPLY WAIT TIME EXCEEDED ?
YES
NO
OWN EI SET ?
NO
YES
YES
OWN EI SET ?
NO
YES

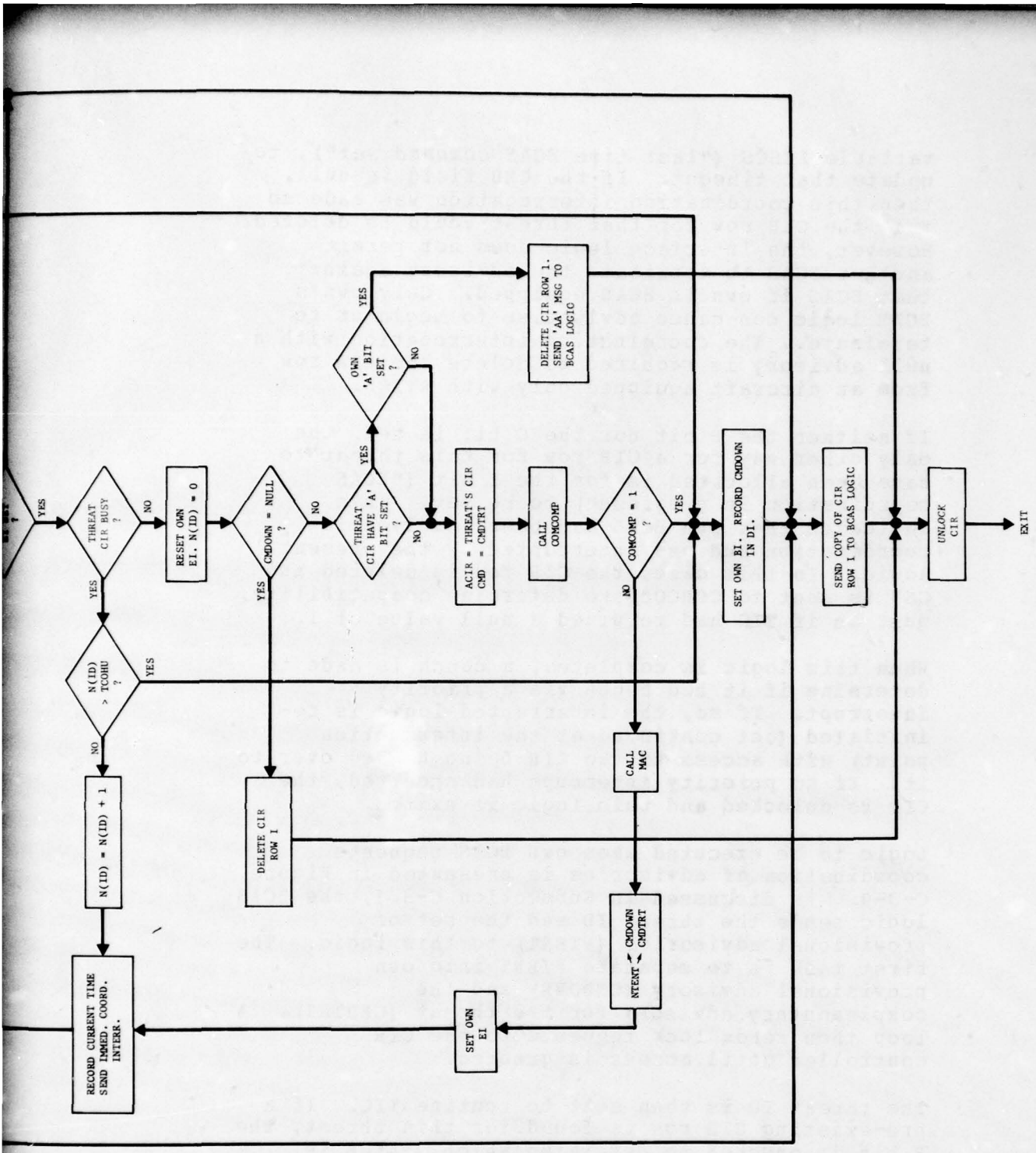


FIGURE C-3-4
COORDINATION LOGIC INITIATED BY OWN BCAS

set") is updated to the current time. If BCAS is the responsible system and CMDOWN is not null, the BCAS timeout variable LTBCS ("last time BCAS command set") is updated to the current time. An intracomputer message from the BCAS logic with a null CMDOWN implies that BCAS desires to drop advisories for this target, which is no longer a threat; LTBCS is therefore not updated in this case.

A coordination interrogation is sent to the target aircraft if it is equipped with ATARS or BCAS. The current time is also recorded in order to avoid an indefinite wait for a coordination reply that is not forthcoming. If CMDOWN = null, implying that CMDTRT = null, CMDTBT is nevertheless sent to the target aircraft in a coordination interrogation. The target aircraft, if it were ATARS equipped, would then use the null BCAS advisory complement to delete its CIR row corresponding to own.

Since this logic does not differentiate on the basis of the B or C bit being set, the coordination interrogation is sent to the threat regardless of which system is responsible for this conflict. If that system is ATARS, the coordination interrogation enables the threat aircraft, if ATARS-equipped, to maintain its ATARS advisory as long as own BCAS perceives a hazard. Thus, when the threat drops out of ground surveillance before the danger has been eliminated, BCAS refreshes the ATARS-generated advisory until the conflict is resolved. If the responsible system is BCAS and the threat is ATARS-equipped, the continued coordination interrogation permits the threat to maintain its BCAS advisory complement associated with own, so that ATARS would not send it an advisory (to evade some threat other than own) which thwarts own's resolution.

If TIC returns a null value of I, routine COMCOMP is called to ensure that own's provisional advisory is compatible with own CIR. If an incompatibility is detected (COMCOMP returns a

value of 0), a multi-aircraft logic routine (MAC) is called to reselect the provisional set of advisories. MAC returns a value of NTENT, which must once more be separated into own provisional advisory and its provisional advisory complement.

If the threat aircraft is ATCRBS-equipped, BCAS is designated the responsible system, and this logic is exited. If the threat has ATARS or BCAS, it is necessary to perform air-to-air coordination. A CIR row is allocated to the threat's ID and the E bit is set, to indicate that BCAS coordination is in progress. A local counter N(ID), indexed on the ID of the threat, is also initialized, in order to prevent against looping indefinitely if the threat's CIR is malfunctioning and remains locked. A coordination interrogation (containing own DABS ID, own A bit, and the BCAS provisional advisory complement CMDTRT) is immediately transmitted to the threat. If no reply is received by the time the reply wait interval has elapsed, own computer commits to BCAS for separation from the threat, provided own E bit is set. If it is not set, coordination had previously been accomplished and the logic is simply exited.

If a coordination reply is received before the reply wait interval has elapsed, the E bit is similarly checked. If this is indeed the initial coordination cycle, the coordination reply is examined to determine whether the threat's CIR was busy at the moment it received own's coordination interrogation. If it was busy, the same coordination interrogation is immediately retransmitted, provided that the number of retransmissions is not excessive. An excessive number of coordination interrogation retransmissions is reached when N(ID) > TCOHU (threat CIR is obviously hung up). If the number of retransmissions is found to be excessive, own computer commits to BCAS. If not, N(ID) is incremented to reflect the current retransmission.

If the coordination reply contained the threat's CIR, EI and N(ID) are reset. CMDOWN is then

checked to determine whether it is null, indicating that BCAS is terminating advisories and the coordination interrogation was only to inform the target aircraft of this fact. If CMDOWN is null, the CIR row corresponding to this target is deleted, and the logic is exited. If CMDOWN is not null, both own and threat's A bits are checked. If both are set, ATABS is responsible for assuring separation of this pair and BCAS must inhibit its advisories. The CIR row associated with this threat is deleted and the logic is exited, while sending an 'AA' message ("both own and threat are being protected by ATARS") to own BCAS logic. ATABS will subsequently uplink a CIR row for this threat.

If at least one aircraft in this pair does not have its A bit set, the threat's CIR and the BCAS provisional advisory complement sent to the threat in own's coordination interrogation, are sent to routine COMCOMP. If COMCOMP returns a value 0, it is deduced that the threat rejected the provisional advisory complement, since the threat will have used an identical COMCOMP logic to test for compatibility. The multi-aircraft logic MAC is then called, and it uses the threat's CIR, own CIR and own's track of the threat, to select a new set of advisories which is universally compatible. Upon return of control from MAC, another coordination interrogation is immediately sent, with the new advisory complement.

If COMCOMP returns a value 1, it is deduced that the threat accepted the advisory complement. Own computer then commits to BCAS. When exiting this logic, a final copy of the CIR row assigned to ID is sent to the BCAS logic.

Several auxiliary functions have been omitted from the preceding flow charts for the sake of clarity. DABS interrogations from ground sites will contain not only resolution advisories and A bits, but also traffic advisories called Proximity Warning Indicators (PWI's). Such data on nearby target aircraft is also available from BCAS, which refers to them as Intruder Position Data (IPD's). In

order to assure uniqueness of traffic advisories on the cockpit display of a BCAS aircraft, the following filter has been established. If own A bit is set, only ATARS-originated PWI's will be presented to the pilot. BCAS originated IPD's are presented when own A bit is not set. An exception is made whenever BCAS is displaying a BCAS-generated resolution advisory for a threat. This is done to eliminate the possibility of displaying resolution advisories for which no corresponding PWI display exists. BCAS will periodically check own A bit (see Table C-3-1, own 'A' bit request message), and display or inhibit the IPD's it generates.

Certain actions taken by the CIR ccntroller should also be clarified. When responding to own BCAS's request for coordination, as when an intra-computer message from Table C-3-1 is received, that request is honored immediately if the CIR is available. If the CIR is locked, the request is held in a WAIT state until it becomes free, and is then honored. This is done in order to free the BCAS logic from the need to periodically re-issue coordination requests when the CIR is unavailable. An endless loop in the CIR controller must cycle through the LTACS variables associated with each CIR row, in order to delete rows that have not been updated recently enough.

As described in the BCAS collision avoidance algorithms, cockpit display information can originate from either the BCAS logic or the ATARS-BCAS interface, or both. These functions send display requests (add information, delete information, alter information) to a stack called the Display Request Queue (see Figure C-3-5). An activity called the Display Function accomodates these requests one at a time, creating display vectors which it writes into the Display List. The Display Driver program reads these vectors and transforms them into display commands for the cockpit display. The details of these operations are described in the BCAS collision avoidance algorithms (Appendix K in Volume III of Reference 3).

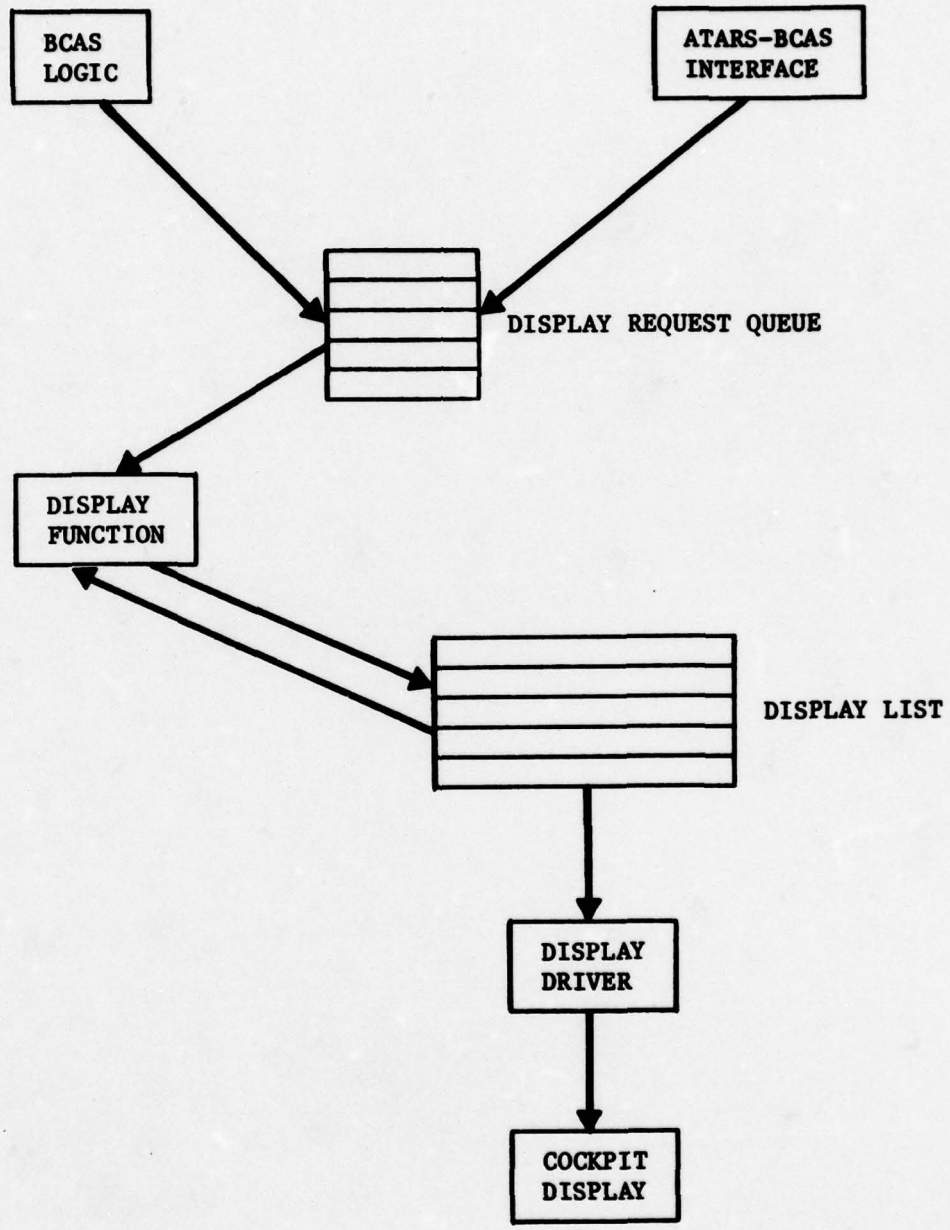


FIGURE C-3-5
DISPLAY INFORMATION FLOW

C-4. IMPACTS ON EXISTING DESIGNS

In this section, the additional capabilities that the existing systems would need in order to support this interface are summarized.

C-4.1 Communications

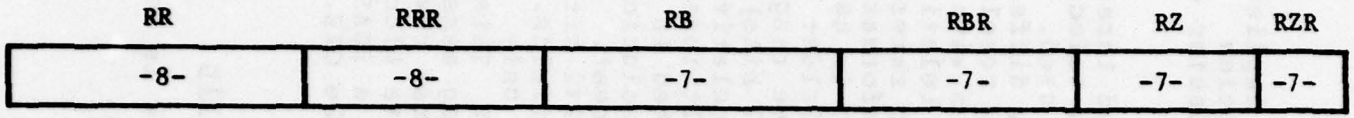
Various additional message types were implied in the foregoing discussion. This subsection describes the requirements for the transfer of data air-to-air and air-to-ground.

In order to identify an ATCRBS-equipped threat aircraft, that aircraft's position and velocity (relative to own) and Mode-A code are used. Since rectangular coordinate systems used by different computers in tracking cannot be easily resolved, threat tracks are expressed in a system with the subject aircraft at the origin (i.e., relative range, bearing and altitude, and their rates). A data block used to communicate this information is presented in Figure C-4-1. This block is 44 bits long. It consists of the following fields: RR (relative range, 8 bits), RRR (relative range rate, 8 bits), RB (relative bearing, 7 bits), RBR (relative bearing rate, 7 bits), RZ (relative altitude, 7 bits) and RZR (relative altitude rate, 7 bits). This data block is transmitted in a long interrogation when ATARS uplinks a resolution advisory that applies to an ATCRBS threat. (A long message in the DABS protocol is 112 bits and can transfer data in general purpose fields. A short message of 56 bits is used when only surveillance functions are performed.) This long message would immediately follow a long message which contains the contents of the first row of the CIR for this threat. The same data block is used in a long reply message whenever a BCAS aircraft or the ground system reads the CIR.

C-4.1.1 Ground-to-Air Messages

C-4.1.1.1 Setting the ATARS Service Bit

The most common activity on the uplink is for



RR = RELATIVE RANGE

RRR = RELATIVE RANGE RATE

RB = RELATIVE BEARING

RBR = RELATIVE BEARING RATE

RZ = RELATIVE ALTITUDE

RZR = RELATIVE ALTITUDE RATE

FIGURE C-4-1
ATCRBS THREAT RELATIVE TRACK BLOCK

ATARS to set the A bit (ATARS service bit) for aircraft within the ATARS service zone. This must be done for each aircraft each scan. Clearly, it is desirable to do this as a part of the short surveillance interrogation or long interrogation which is made of each aircraft each scan. The method of multisite coordination described in Appendix G, which provides for communication between sites through the transponders, requires that four bits be used in the short surveillance interrogation. These four bits represent site ID's. Each site sets the site ID bit corresponding to its ID in the surveillance interrogation each scan for aircraft that are in the ATARS service zone. The corresponding bit in the site ID in the CIR is then set. The avionics maintains a timer for each of the four site ID's in the CIR. Whenever the site ID bit is set in the surveillance interrogation, the timer for that ID is reset. If the timer for one site ID reaches a certain threshold, the avionics automatically resets that site ID bit to zero in the CIR. Every time the avionics receives a surveillance or long interrogation, the site ID field in the CIR is updated, all four site ID bits are observed, and if at least one site ID bit is set, the A bit in the CIR is set.

C-4.1.1.2 Uplink of ATARS Messages

In uplinking ATARS resolution advisories it must be possible to specify the maneuver that is being issued against each threat and to transmit a 24-bit DABS ID to identify each DABS threat. ATCRBS threats must be identified by the ATCRBS track block described in Section C-4.1. Since the 24-bit DABS ID's and the resolution maneuver fields for two DABS threats could not be contained in one long message, a protocol which uses one long message to transfer the data pertaining to each DABS threat is required. The protocol requires two long messages (one containing the maneuver and the Mode A code, the other containing the ATCRBS track block) to transfer data pertaining to a single ATCRBS threat. Two long message types are required to support this

protocol. The required data is shown in Figure C-4-2.

The first message type is the resolution advisory message. It is used to send the resolution maneuvers to the CIR and to the ATARS display. The LR bit is used to inform the avionics that this uplink is the last uplink of information for the CIR for this scan. The CIR Controller locks the CIR when it receives the first uplink addressed to the CIR and keeps it locked until a message with LR = 1 is received. To protect against the event when the DABS sensor is unable to complete uplink of the CIR information, the CIR will automatically unlock a specified time after being locked. If the entire uplink for a complete scan is not received by the avionics, any partial information received will be discarded.

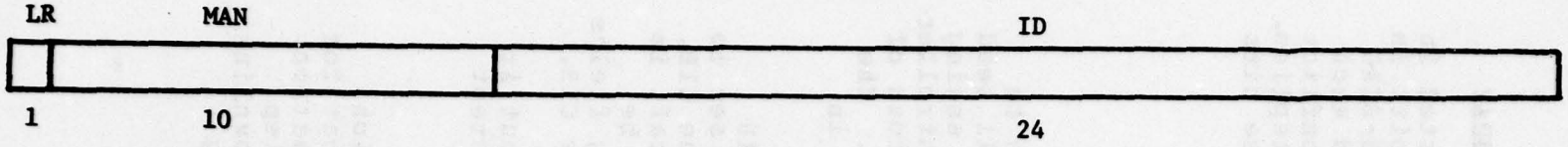
The MAN field is a ten-bit field containing the resolution advisory generated by ATARS to protect against a single intruder. It is coded exactly like the D field in the CIR (see Table C-2-1).

The ID field in the resolution advisory message contains the 24-bit DABS address of the threat associated with the advisory in the MAN field, if the threat has a DABS transponder. If the threat is an ATCRBS aircraft, the ID field contains the Mode A code of the aircraft and it is understood that the next uplink will contain the ATCRBS Track Block which is used to identify the threat.

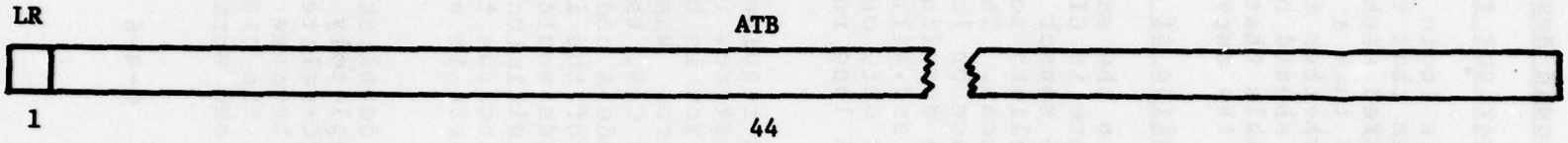
The second ATARS message type on the uplink is the ATCRBS track block message. It is used to uplink the ATCRBS track block described in Figure C-4-1 when an advisory due to an ATCRBS aircraft is being uplinked.

It is clear that this protocol for ATARS uplinks has the flexibility to handle unlimited numbers of resolution advisories.

RESOLUTION ADVISORY MESSAGE



ATCRBS TRACK BLOCK MESSAGE



LR = Last Row of CIR

MAN = Resolution Advisory

ID = 24 Bit DABS Address of Intruder

ATB = ATCRBS Track Block

FIGURE C-4-2
REQUIRED FIELDS FOR ATARS UPLINK
OF CIR MESSAGES

C-4.1.2 Air-to-Ground Messages

C-4.1.2.1 Modifications to Surveillance Reply

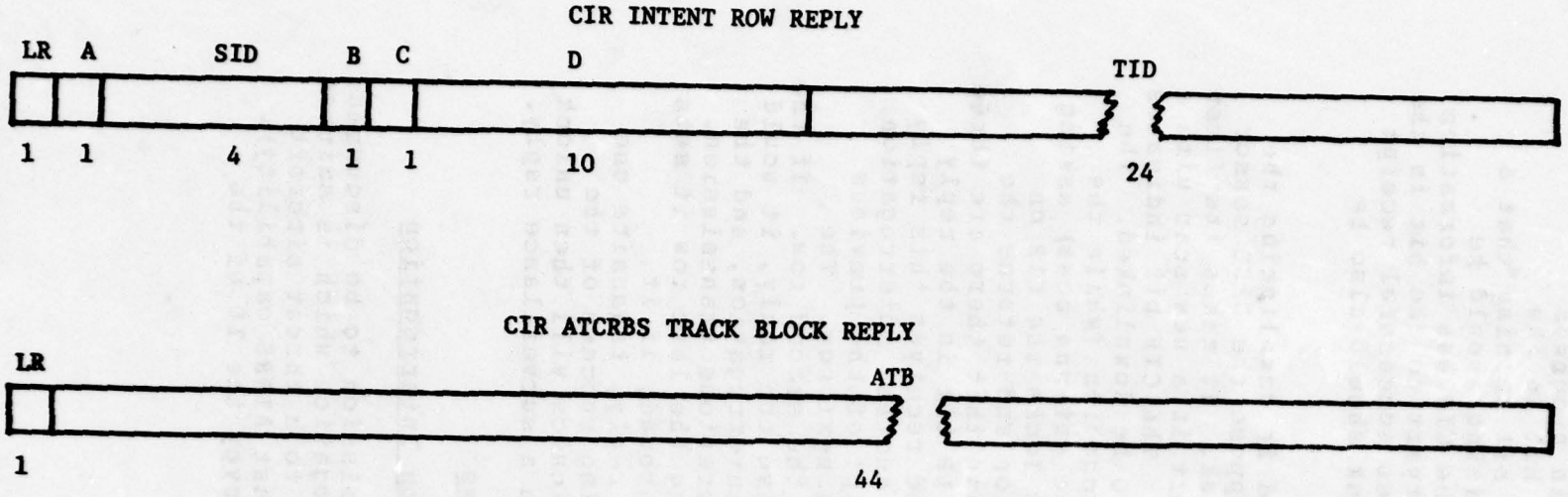
The ATARS multisite logic development reported in Appendix G requires that the four site ID bits in the CIB be downlinked each scan. The ATARS-BCAS interface requires that a bit be downlinked each scan to indicate whether the CIB has any conflict information which should be read via long replies. It would be desirable that all five of these bits be made a part of the surveillance reply.

C-4.1.2.2 Downlinking of the CIB

When the CIR bit in the surveillance reply indicates that there is CIB information to downlink, the DABS sensor must immediately schedule long downlinks so that the CIB can be read on the same scan. The DABS sensor will send another surveillance or long interrogation asking for CIB data to be downlinked. The CIB Controller will lock the CIB and will then cause the rows of the CIB to be read out, one per long reply. The content of the CIB long reply is presented in Figure C-4-3.

A special reply is required to indicate "CIB Busy". LR is a last row indicator. It is set to one when the last row is being sent from the CIB. Otherwise it is zero. When an ATCRBS aircraft is represented in the CIB, the TID field will be filled with the Mode A code. The remaining fields are simply copies of the information in the CIB. The A and SID fields would be duplicated unnecessarily in multiaircraft encounters but it is convenient to include them in the CIB intent row message and there is no harm in the duplication.

The mechanism for downlink of CIB information should be made completely independent of that for the downlink of ATC-related or other information. This is desirable because BCAS units may also request readout of the CIB, and the long downlink protocol could become scrambled if two long



LR = Last Row Indicator

A = ATARS Service Bit

SID = Site ID Field

B = Resolution Committed to BCAS

C = Resolution Committed to ATARS

D = Own Intent with Respect to This Intruder

TID = 24 Bit DABS Address

ATB = ATCRBS Track Block

FIGURE C-4-3
CONTENT OF CIR REPLY MESSAGES

downlink transactions were in progress simultaneously. A separate bit in the surveillance reply from the bit meaning that a long downlink message is waiting should be provided to indicate that the CIR has information to be downlinked. A counterpart to the bit in the interrogation which indicates successful receipt of the previous long downlink should also be provided.

The entire sequence involved in downlinking the CIR is now illustrated. Suppose the DABS sensor has no long message to uplink. It makes its first interrogation of the aircraft in a new scan with a surveillance interrogation. The CIR bit indicates that there is information to be downlinked. The sensor sends another interrogation (while the aircraft is still within the antenna beam) asking for CIR data. The avionics locks the CIR on receipt of this interrogation and returns the first row of the CIR. Assume that there are three rows in the CIR. Then the LR bit in the reply will be zero. If the ground receives this reply successfully, it will make another interrogation indicating successful receipt of the previous downlink and asking for the next row. The avionics will respond with the second row. If the ground should fail to receive one reply, it would indicate this in the next interrogation, and the avionics would repeat the previous transmission. When the avionics is sending the last row it sets LR = 1 in the reply. The ground, if it successfully receives this reply, transmits one last interrogation indicating success of the previous downlink. The avionics will then unlock the CIR and will reply with a surveillance reply.

C-4.1.3 Air-to-Air Messages

C-4.1.3.1 BCAS Coordination Interrogation

The first air-to-air transmission to be discussed is the coordination interrogation which is emitted by a BCAS and is addressed to a threat aircraft (when the threat has at least ATARS capability). This interrogation must convey the ID of the

sender, the sender's A bit, and the BCAS advisory complement, which is used both in BCAS coordination and as an advisory selection constraint in subsequent (but time-overlapping) conflicts. This data involves enough bits that a BCAS unit will be required to transmit a long interrogation for coordination with a threat. The ID and A bit of the sender and the BCAS advisory complement can be easily fit into a long message, using the intent codes listed in Table C-2-1 for the BCAS advisory complement. For normal active ranging, BCAS can use the short interrogation.

C-4.1.3.2 BCAS Coordination Reply

The BCAS or ATARS avionics replies to a coordination interrogation with a series of long replies that transmits the contents of the CIR. The same protocol described in Section C-4.1.2.2 is used. At least one long reply must be made to the coordination interrogation even though there is no conflict information in the CIR. The reply is still required in order to convey the value of the A bit to the requesting BCAS.

C-4.2 Changes to the ATARS Ground Algorithms

The following changes to the ATARS ground algorithms are required to implement the ATARS-BCAS interface. The actual detection and resolution process within ATARS is nearly unchanged. The only modification is that ATARS must check to see if BCAS has already taken responsibility for a pair before generating resolution advisories for that pair. In normal situations, BCAS will not take responsibility if both aircraft are within ATARS coverage. However, it is possible that at the time of conflict detection, one of the aircraft was below the DABS coverage floor but was seen by BCAS. If this aircraft pops up into ATARS coverage during the resolution, ATARS is not permitted to generate advisories on its own, but must accept the advisoriess generated by BCAS for that pair.

A surveillance coverage floor map must be added to

ATARS. When a BCAS aircraft is near the floor of coverage, ATARS ceases sending the message to BCAS that prevents BCAS active interrogations. BCAS may then begin to provide protection against pop-ups or to provide protection as the BCAS aircraft drops below the floor of coverage. In addition, ATARS must maintain a service zone map and must provide logic based on this map for managing the site's ID bit in the transponder.

The capability must be added to ATARS to receive the CIR information on the downlink. This information is transmitted on the downlink via multiple long downlinks each scan during the conflict. ATARS must search the threat ID's from the downlink and correlate them with conflict table entries in the ATARS data base. If a conflict is indicated by the downlink that is not found in the ATARS pair records, a new pair record must be created for that conflict and added to the ATARS data base.

C-4.3 Requirements on the DABS Sensor

In order that the entire CIR be read in one antenna beamwidth, the DABS sensor algorithms must manage the long message protocol for downlinking the CIR. The sensor must recognize that the CIR bit is set in the surveillance reply and must immediately schedule interrogations that elicit long replies from the CIR. The bit indicating success or failure of the previous downlink must be set appropriately in each interrogation. The sensor must recognize the LR (last row) bit in the long reply and send one final interrogation which unlocks the CIR. The sensor must also recognize the "CIR Busy" reply and must continue to schedule downlinks from the CIR until readout has been successful.

C-4.4 Requirements on the ATARS or the Combined ATARS-BCAS Display

The major requirement on the ATARS display, or on the display in a BCAS aircraft that is used to present either BCAS or ATARS advisories, is that

the display must include the CIR and logic to update it based upon inputs from ATARS or another BCAS, or upon inputs from own BCAS. When the CIR contains conflict information, it must be transmitted to the ground on every scan, or to the other BCAS whenever a BCAS coordination interrogation is received (this happens once per BCAS cycle for the duration of the conflict).

The CIR consists of one bit indicating that own aircraft is within ATARS coverage, four bits indicating which sites are providing ATARS service for own aircraft, and rows of data containing information about other threats in conflict with own aircraft. Each ATARS ground site sets the one of the four site ID bits corresponding to its ID every scan. Each time a surveillance interrogation is received from the ground, the CIR logic sets the single ATARS coverage bit if any one of the four site ID's is set.

A DABS threat has one row in the CIR. An ATCRBS threat has two. The logic in the display must be able to correlate threat ID's from the incoming data with ID's already existing in the CIR. When it finds a match, it must update the appropriate row or rows. It must delete a row on command from ATARS or own BCAS and must be able to recognize that a row does not exist for a particular ID and create a row for it. In making this search for ATCRBS ID's it must be able to compare a set of relative range, bearing, altitude, range rate, bearing rate, and altitude rate data with that already existing in the CIR.

The display, before accepting incoming data and incorporating it into the CIR, must check the advisories in the incoming data for compatibility with all other advisories already existing in the CIR. It does this by indexing a matrix of bits with the incoming advisory and an existing advisory from the CIR. If the advisory is incompatible, the incoming data is ignored and is not added to the CIR.

The CIR must also have a lockout capability that

prevents two different requests for operation on the CIR from being honored simultaneously. For example, own BCAS cannot change the CIR during the period that the ground ATARS algorithm is in the process of reading out the CIR with multiple long downlinks. The lockout logic, however, must have a feature to preempt the lockout in the special case when the CIR is locked because own BCAS has made a coordination interrogation of a second BCAS, and has also received a coordination interrogation from that BCAS before receiving the reply to own's interrogation. In this case, the lockout is preempted if own DABS ID is a higher order ID than the DABS ID of the other BCAS.

The CIR must include a protocol for managing the transmission of CIR data. It must recognized by a zero value of a particular bit in the interrogation that a previous long reply was not received by the ground and must be able to repeat that long reply. It must sense the proper bits in the interrogations, and lock the CIR, unlock the CIR, or reply with a "CIR Busy" message as appropriate.

The ATARS display must be changed to accept the new ATARS uplink formats.

C-4.5 Requirements on the DABS Transponder

Every DABS transponder which is to be used with an ATARS or a combined ATARS-BCAS display must have the capability to transmit long replies.

C-4.6 Requirements on the BCAS Logic

Either the active BCAS or the Full BCAS must have provision to terminate routine, active surveillance interrogations under command from the ground ATARS algorithms. ATARS will permit active interrogations only when the BCAS aircraft is near the boundary of ATARS coverage. The squitter lockout bit in the current surveillance interrogation will be used to inhibit active interrogations. When this bit is set, the DABS transponder on the BCAS aircraft will refrain from

making squitter replies and the BCAS will refrain from making active interrogations.

Flow charts for the specific logic to implement the ATARS-BCAS interface within BCAS have been developed. This logic specifies the BCAS-BCAS coordination logic required to make the ATARS-BCAS interface work. This logic requires that BCAS be able to make repeated interrogations to receive several long replies in quick succession from an ATARS or a BCAS-equipped intruder. This capability is used by own BCAS to read the CIR from another BCAS or ATARS intruder.

The BCAS threat logic, for positive resolution advisories that are generated because of an ATCRBS intruder, must use look-ahead times that are less than those used by ATARS in the same circumstances. This will ensure that ATARS will normally be the system to generate advisories for encounters against ATCRBS intruders as well as for encounters against ATARS or BCAS-equipped aircraft.

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APPENDIX D

DEVELOPMENT OF AN INTERFACE BETWEEN ATARS AND TERMINAL CONFLICT ALERT

W. D. Love
H. C. Strunz

D-1. INTRODUCTION

This appendix describes development of the interface between Automated Traffic Advisory and Resolution Service (ATARS) and Terminal Conflict Alert. Terminal Conflict Alert is currently in operation at a number of terminal Air Traffic Control (ATC) facilities with Automated Radar Terminal System (ARTS)-III equipment. After ATARS has been installed at a facility with Terminal Conflict Alert, there would be a great liklihood that both systems would alert in a conflict situation. If a consistent set of logic and a consistent set of operational procedures were not in effect for the two systems, the resulting alerts could be confusing and counterproductive. It was the purpose of this study to develop an interface between ATARS and Terminal Conflict Alert that would provide this consistency.

The first step in this activity consisted of exercising the Terminal Conflict Alert logic and the ATARS resolution advisory logic with recordings of live traffic data. This study suggested a significant degree of incompatibility between the two functions in that either system might be first to alarm in any particular encounter. As a result, an investigation was conducted of the feasibility of incorporating a Conflict Alert emulator into the ATARS logic to provide more consistency in the sequencing of alerts from the two systems. If this could be done, then it would be possible to remove Terminal Conflict Alert from ARTS and to provide the alerts to the controller from the ATARS system after the Discrete Address Beacon System (DABS) and ATARS had been installed at a terminal location.

The purpose of the investigation resulting from this first step was to replace the current controller alert module of ATARS with a Conflict Alert emulator, match its performance as closely as possible to that of Terminal Conflict Alert, and run a variety of computer-simulated aircraft encounters to compare the performances of the two. It was also a goal to develop resolution advisory

logic for ATARS, consistent with Conflict Alert, that would retain as much of the original logical structure of ATARS as possible. An approach to providing a Conflict Resolution service to the controller from the ATARS system also evolved from this study.

To evaluate the fidelity of the emulator, the full Terminal Conflict Alert algorithm and the emulator were programmed, and a Monte Carlo simulation program was used to directly compare the performance of the two. The simulated encounters included a variety of speeds and angles of approach, and included encounters with straight flight and with turning maneuvers.

D-2. ATARS-TERMINAL CONFLICT ALERT INTERACTION

D-2.1 Interaction During Visual Weather Conditions

An analysis was performed of the interaction between ATARS and Terminal Conflict Alert using recordings of live traffic. In this study, the time of generation of ATARS advisories and the time of Terminal Conflict Alert warnings were noted when both systems were exercised with a common aircraft encounter test set. This test set consisted of eight hours of data obtained from ARTS III extractor tapes. (Reference 1 explains how this data was collected and reduced.) Only aircraft controlled by ATC are included in the samples. All samples were taken during visual weather conditions. The data represents air traffic at three airports: Washington National (2 hours), Miami International (4 hours), and Chicago O'Hare (2 hours).

There are three alert-generating modules in Terminal Conflict Alert: LINCON, MFMAMS, and PROCON. LINCON, the most significant, utilizes linear projection to establish vertical and horizontal conflict time intervals. If these intervals overlap, the earliest time in the overlap region is the time of violation and this is compared with a look-ahead time threshold to determine potential conflicts. MFMAMS is a maneuver-sensitive module. Cross-track deviations are utilized to indicate when a maneuver is in progress in the horizontal plane. Various separation and flight geometry criteria are then used to predict potential conflicts. A vertical acceleration estimate is used to determine when vertical maneuvers are present. When they are present, the vertical acceleration is also used to predict conflicts. PROCON generates alerts by comparing current horizontal and vertical separation to fixed thresholds. It also has a feature which tests for a predicted conflict in one specific type of turning encounter.

The Conflict Alert algorithm employed reflects the

logic and parameters in use at Houston as of January 1978. It is described in Reference 2. The ATARS version utilized included changes that had been recommended prior to the same date. Only minor changes to correct flow chart errors or to adapt the algorithms to the current test environment were made in programming Conflict Alert. There are two areas where the tested algorithm employs these changes. The first concerns a function in Conflict Alert which sets the turn bits (left or right) for tracked aircraft, based on tracked velocity from two scans earlier and current reported position. In the tested module, velocities and positions provided by the data reduction process were employed rather than the outputs of the ARTS tracker. Secondly, the ARTS tracker normally provides an estimate of vertical acceleration for each aircraft, based on various criteria. In the tested algorithm, vertical acceleration was simply computed from the change in tracked vertical velocity, in one scan. Table D-2-1 shows the values of the significant Conflict Alert parameters.

The version of ATARS that was studied was programmed from Reference 3 with a few modifications. All aircraft were treated alike. No parameter modifications for different types of encounters were used. Table D-2-2 presents the ATARS parameters that were different from those in Reference 3. These modifications to the ATARS parameters were found to be necessary to avoid undue interference with normal ATC procedures inside the Terminal Control Area (TCA) boundaries in visual weather conditions. Reference 4 reports on the study that made these recommendations for changes.

It was found that 26 aircraft encounters in the eight hours of data produced Conflict Alert warnings. Four of these elicited positive ATARS advisories and three others produced negative ATARS advisories. With Conflict Alert, only one parameter set was used and this was the set appropriate for areas outside the immediate airport area (area type III). Conflict Alert

TABLE D-2-1

SIGNIFICANT CONFLICT ALERT PARAMETER VALUES

PARAMETER	VALUE
LKHA	40 SEC.
DZIMQ	275 FT.
ASEQ	375 FT.
PSEQ	1.2 NMI.
LSEQ	1.2 NMI.
LMDIMQ	0.5 NMI.
LDAQ	0.3 NMI.
TOCIMQ	25 SEC.
TOMIMQ	25 SEC.

TABLE D-2-2

ATARS PARAMETERS THAT WERE MODIFIED

PARAMETER	VALUE
TCMD	30 SEC
ADET	7.5 SEC^2
BDET	0.025 NMI^2
MDTHSQ	0.16 NMI^2

employs other smaller parameters in area types I and II which are areas immediately surrounding the airport. Thus, the 26 alerts represent an upper bound on the number of alerts that Conflict Alert would have generated in actual operation at these three airports.

For those aircraft encounters which produce both ATARS advisories and Conflict Alert warnings, the lead time, LT, is defined as follows:

LT = Time of ATARS advisory minus time of Conflict Alert warning.

Thus, LT is positive if Conflict Alert generates a warning before ATARS generates an advisory. The lead times associated with the four ATARS positive advisories were -14, 3, 0 and 28 seconds. The lead times for ATARS negative advisories were 0, 2, and 25 seconds. For collision courses in which there is no maneuvering, one would expect lead times on the order of 20 seconds.

Two of the four encounters which produced positive advisories are shown in Figures D-2-1 through D-2-3. Figure D-2-1 shows the X-Y profiles of the two aircraft involved in the encounter that produced the -14 second lead time. Figure D-2-2, which shows the plot of vertical separation vs. horizontal separation as the encounter develops, indicates that the aircraft are generally separating vertically while closing horizontally. ATARS produces a positive advisory at time 665 seconds. (Time is measured in seconds from the beginning of each one-hour sample of data.) The linear projection module of Conflict Alert (LINCON) generates one isolated request for an alert at time 671 seconds, but since this logic requires three requests on five successive scans to generate an alert to the controller, no alert was generated. The present separation module of Conflict Alert (PROCON) generates an alert to the controller at time 679 seconds. The LINCON portion of the Conflict Alert logic projects the vertical separation into the future using current vertical rates to determine if the aircraft will

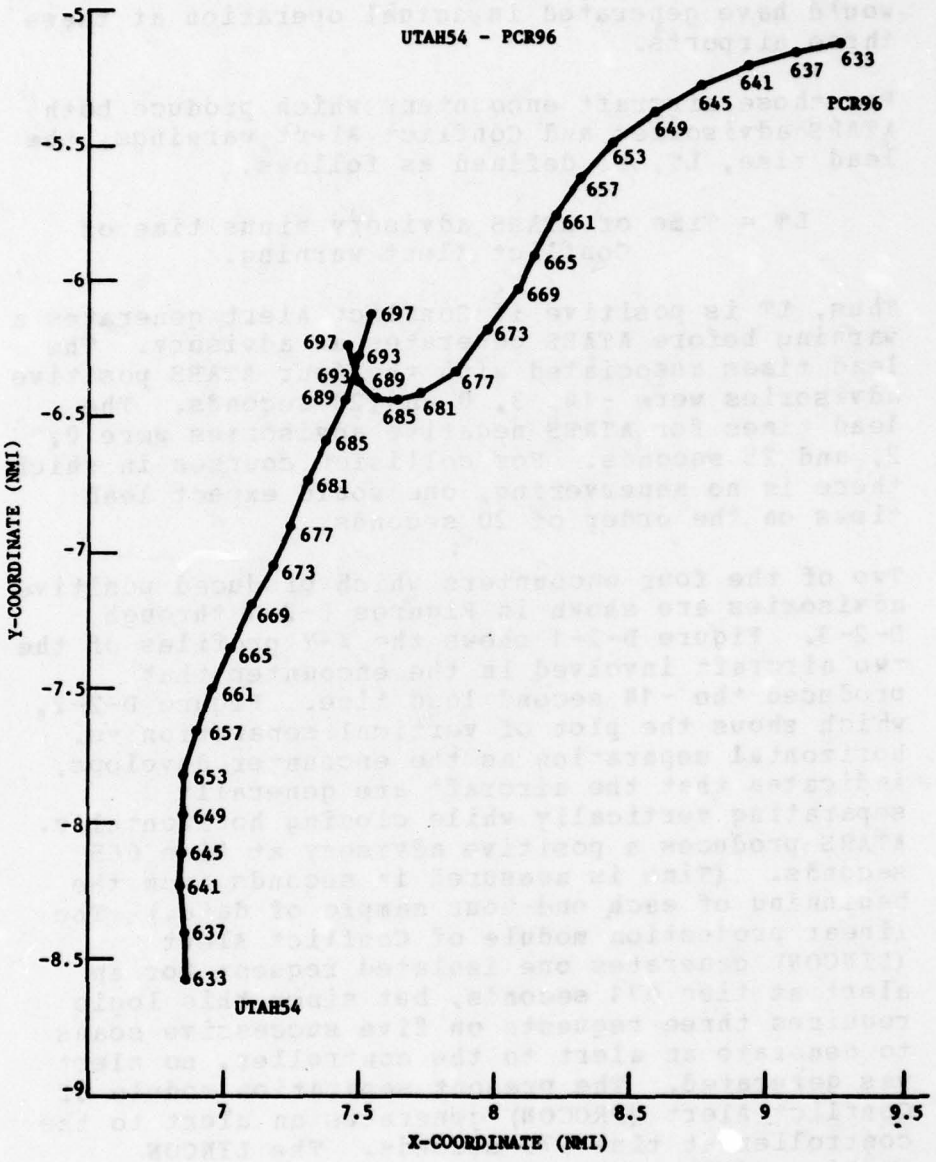


FIGURE D-2-1
HORIZONTAL TRAJECTORIES FOR AIRCRAFT ENCOUNTER WITH NEGATIVE LEAD TIME

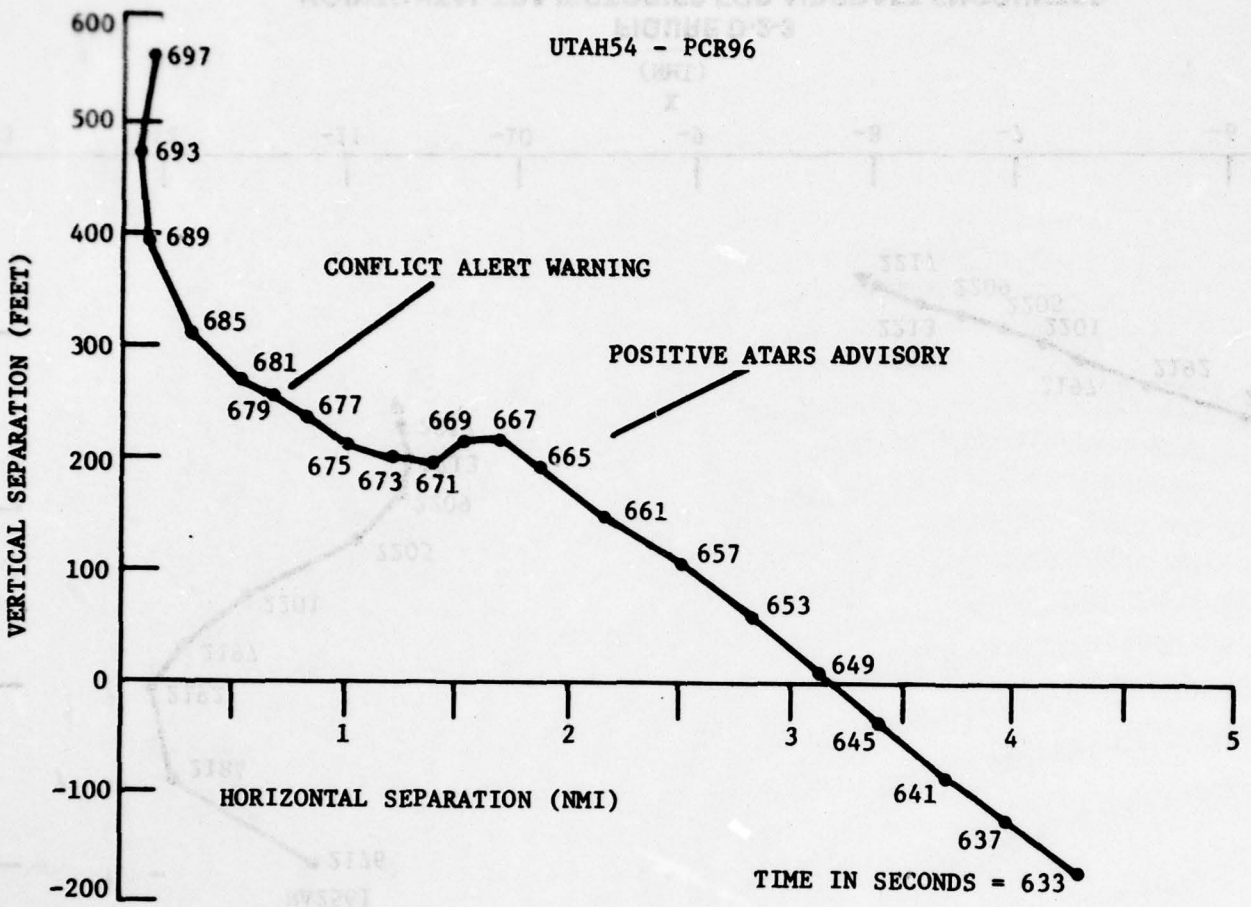


FIGURE D-2-2
VERTICAL VS. HORIZONTAL SEPARATION FOR ENCOUNTER WITH NEGATIVE LEAD TIME

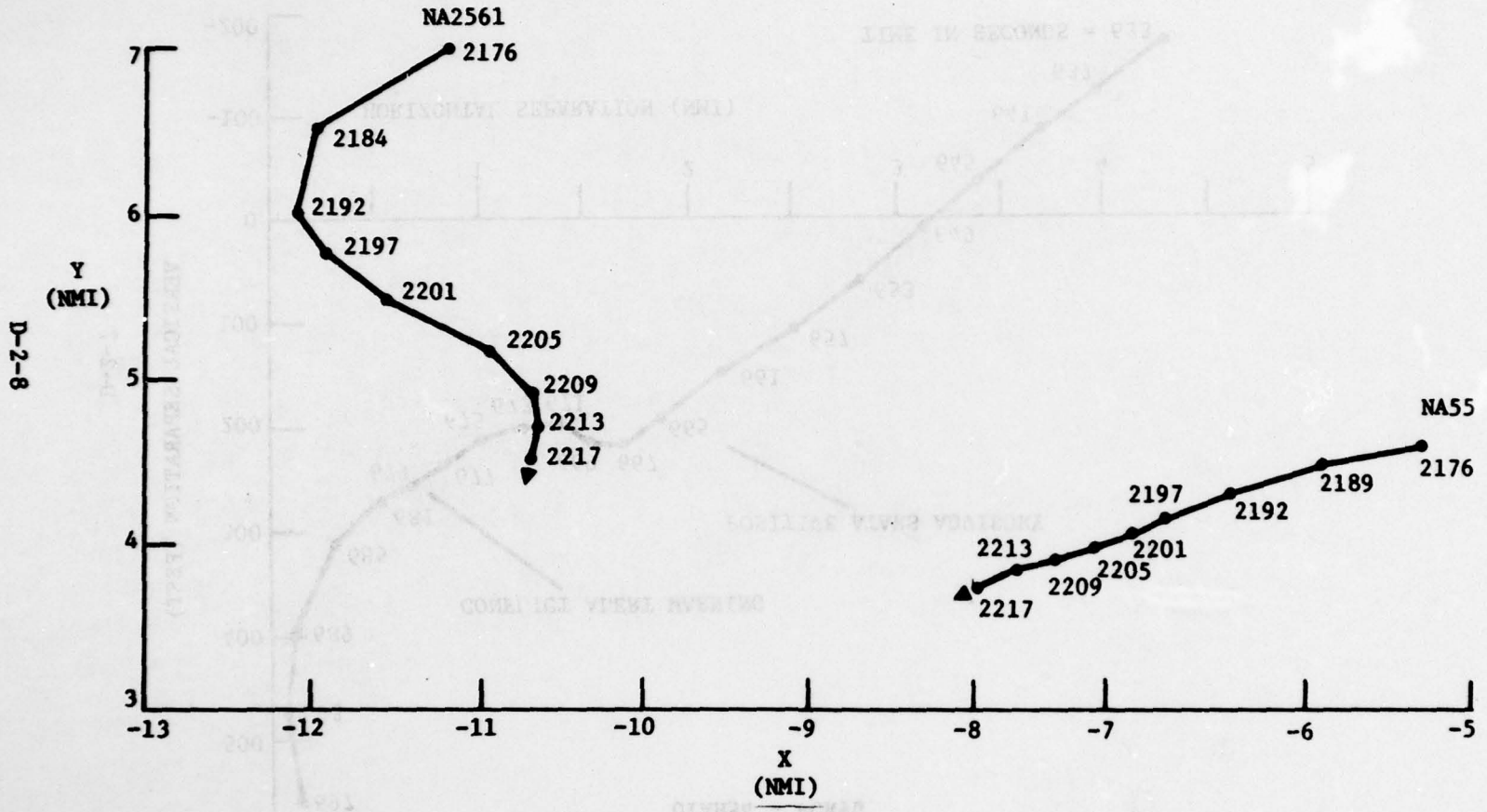


FIGURE D-2-3
HORIZONTAL TRAJECTORIES FOR AIRCRAFT ENCOUNTER WITH ZERO LEAD TIME

be adequately separated vertically during the time period when they are in close proximity horizontally. This logic resulted in a delayed alert from Conflict Alert.

Figure D-2-3 shows the X-Y plot for the encounter that produced a lead time of zero. Both an alert from Conflict Alert and a positive advisory from ATARS occurred at time 2205 seconds. Because of the turn of aircraft NA2561, the time to closest approach (or the tau approximation in the case of ATARS) calculated by both systems dropped rapidly in a nonlinear way. In addition, the three-out-of-five requirement of Conflict Alert resulted in an additional delay in the alert. (Alert conditions must be satisfied on three of five consecutive scans before a warning is generated by the LINCON module of Conflict Alert.) These two conditions caused the alerts from both systems to occur at the same time.

Even though this encounter test set is very small, there are two points of interest:

a) There are substantially more Conflict Alert warnings than ATARS resolution advisories generated by the traffic sample.

b) Those encounters which induce both advisories from ATARS and warnings from Conflict Alert display considerable dispersion of their lead times; even inverted (negative) lead times occur.

There are a number of factors which account, in part, for the above findings. First, the larger number of alerts from Conflict Alert is expected because both the lookahead time is greater (40 seconds compared to 30 seconds) and the horizontal protection distance is greater. ATARS uses a modified tau calculation as a time criterion for an alert. The modification distance in the tau formula is comparable in function to the horizontal protection distance in the Conflict Alert calculations. The modification distance in ATARS is a function of the speeds of the aircraft

involved in the conflict. For typical speeds found in the TCA's, it has a value of 0.25 nmi. This compares to a value of 1.2 nmi for the horizontal protection distance in Conflict Alert.

Conflict Alert and ATARS were developed independently. As a result, there are several areas in which considerably different logic is used. The various thresholds that are utilized in the two systems are therefore not always directly comparable.

Another factor which limits a priori predictability of the lead time is the fact that both systems involve linear projection as the primary means of establishing conflict. Consequently, traffic composed of maneuvering aircraft will often have shorter lead times than traffic in linear motion. This effect will thus be particularly noticeable in terminal areas. In addition to the fact that the linear projections are not directly comparable, there is a further complication in the different manners in which vertical conflict situations are processed.

Although in this study no tracking was performed by either ATARS or Conflict Alert (the positions and velocities produced by the data reduction process were used directly), in the real application additional dispersion in lead time could be produced by the fact that ATARS and Conflict Alert would be using different trackers.

D-2.2 Interaction During Instrument Weather Conditions

When visual weather conditions exist in the terminal area, many controlled aircraft are operating on Visual Flight Rules (VFR) flight plans, and some aircraft operating according to Instrument Flight Rules (IFR) are cleared to maintain visual separation. Under these circumstances, no well-defined separation standards are applied and relatively close separations between aircraft occur routinely. These close separations and visual operations make

the problem of developing an interface between ATARS and Conflict Alert a challenging one, as is evident from the preceding section. However, when instrument weather conditions exist and all aircraft must be controlled by a controller who is working to well-defined radar separation standards, very little interaction is noticed.

Three hours of data collected during instrument weather conditions were processed in the same manner described in Section D-2.1. No ATARS positive advisories were generated by this data. The same ATARS logic and parameters described above were also exercised via real-time ATC simulations in which IFR separation standards were applied. For eight hours of simulated parallel runway operations at Chicago O'Hare airport, no positive advisories were issued. Results of these simulations are presented in Reference 4.

D-3. THE CONFLICT ALERT EMULATOR

A Conflict Alert emulator which would match the operation of the Conflict Alert logic as closely as possible, was to be developed for use within the ATAPS algorithm. This emulator was to be the basis for an integrated ATARS advisory and controller alert logic which would alleviate some of the problems indicated in Section D-2.1. Section D-3 presents the Conflict Alert emulator and shows how its alert times compare to those of Conflict Alert.

D-3.1 Description

Figure D-3-1 is a flowchart of the Conflict Alert emulator test module. It directly replaces the controller alert filter and controller alert processing modules in ATARS and applies to IFR/IFR encounters in terminal airspace. Slow-closing tests are made in both the horizontal and vertical dimensions, based upon the relative aircraft velocities in these dimensions. In cases where the computed velocities show a significant closing rate, a tau threshold is calculated which gives approximately a 40-second warning of the predicted violation of a horizontal separation criterion. In slow-closing or diverging cases, a check is made to determine whether the separation criterion has already been violated. If the calculations predict a violation of separation criteria in both dimensions within the next 40 seconds, the controller alert flag (CAFLG) is set. If this flag has been set on M of the last N scans (where N is the size of the sliding window), then the emulator sliding-window logic issues a controller alert.

D-3.2 Results

D-3.2.1 Sliding Window Logic

Numerous computer runs were made early in the investigation using various window sizes for the controller-alert, sliding-window logic. The best results were obtained with a three-out-of-five

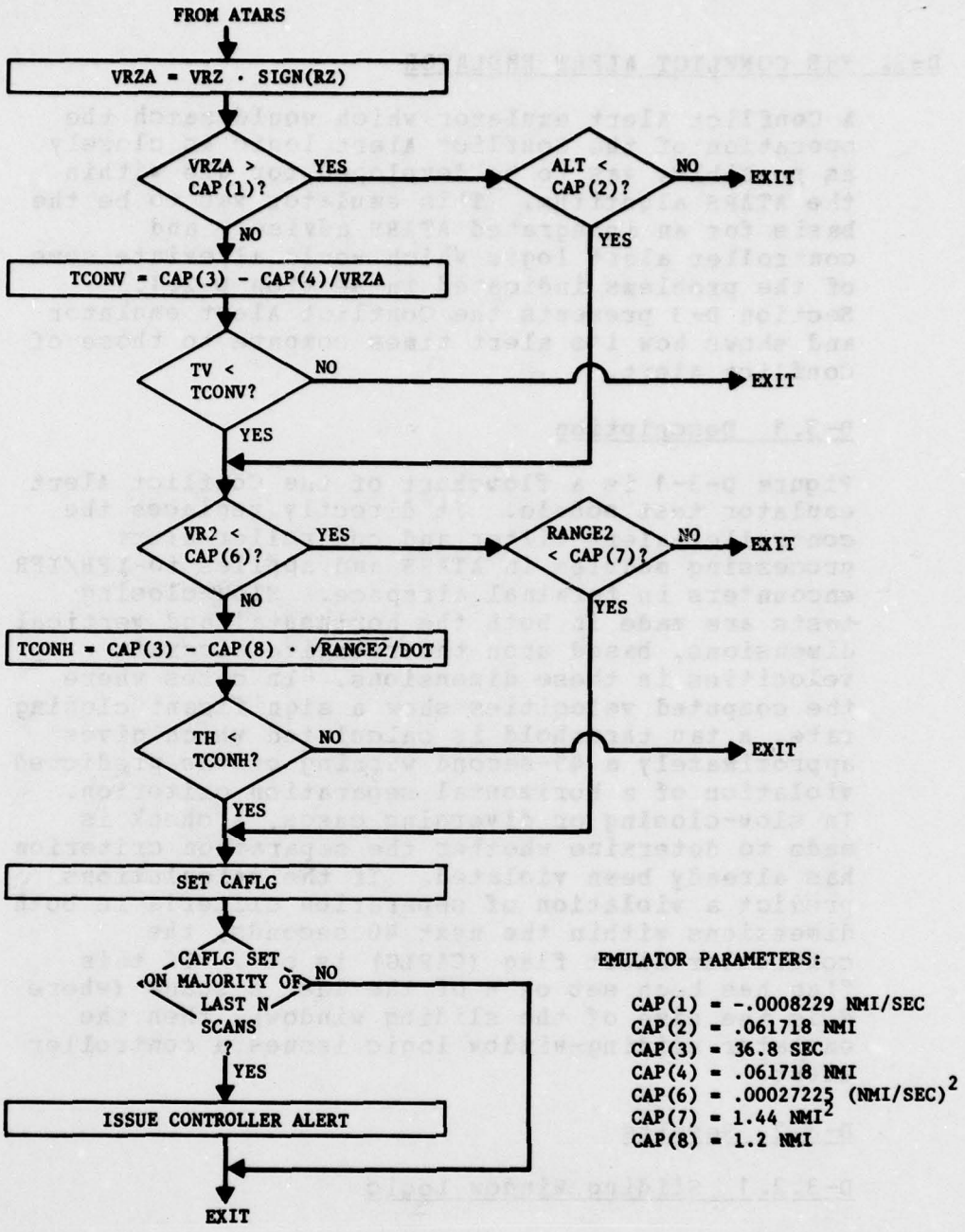


FIGURE D-3-1
CONFLICT ALERT EMULATOR TEST MODULE

logic, the same as used by the primary module of Conflict Alert. The standard of comparison was the overall difference (in scans) between the issuance of warnings by the emulator and by Conflict Alert for the same sets of encounters. Early results showed the three-out-of-five logic to be a distinct improvement over the two-out-of-three logic. In using the three-out-of-five logic rather than the two-out-of-three logic in 432 encounters at various speeds, the standard deviation of the difference in alert times between Conflict Alert and the emulator was smaller by 0.36 scan, and the number of identical performance encounters was 56% greater. Based upon these early results, it was decided to retain the three-out-of-five sliding-window logic in all further tests of the emulator.

D-3.2.2 Final Results

During a series of computer test runs, adjustments were made in the emulator parameters and logic in order to match its alert times as closely as possible to those of Terminal Conflict Alert. The values finally selected for the emulator parameters are shown in Figure D-3-1. The final results of 640 simulated encounters are shown in the histograms of Figures D-3-2 through D-3-5 and Table D-3-1. In these simulations, both aircraft were always in level flight, so that only the horizontal features of the logic were being investigated. The nominal aircraft speeds are indicated by the name of the simulation file. For example, A100250 indicates encounters between a 100-knot aircraft (aircraft number 1) and a 250-knot aircraft (aircraft number 2), while A100100 indicates encounters between two 100-knot aircraft. Note that for simulation files A100250 and A250100, 20 of the 97 encounters indicated on the histograms are turning encounters where aircraft number 2 turns toward aircraft number 1. Lead time is defined here as the time of the Conflict Alert warning minus the time of the emulator warning (in scans). For instance, if Conflict Alert issues a warning two scans before the emulator, the lead time is -2.

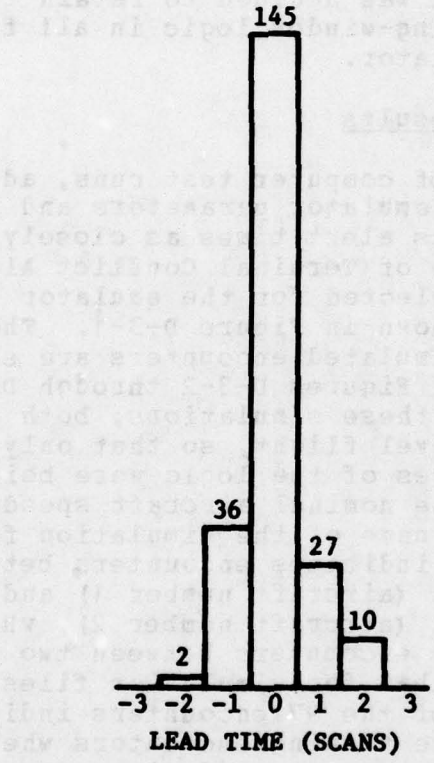


FIGURE D-3-2
HISTOGRAM OF LEAD TIMES FOR SIMULATION FILE A250250

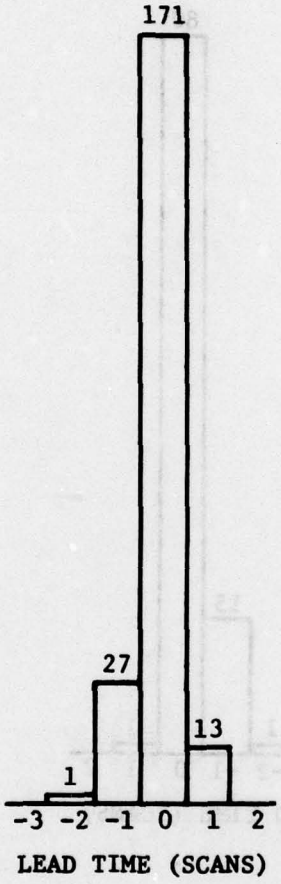


FIGURE D-3-3
HISTOGRAM OF LEAD TIMES FOR SIMULATION FILE A100100

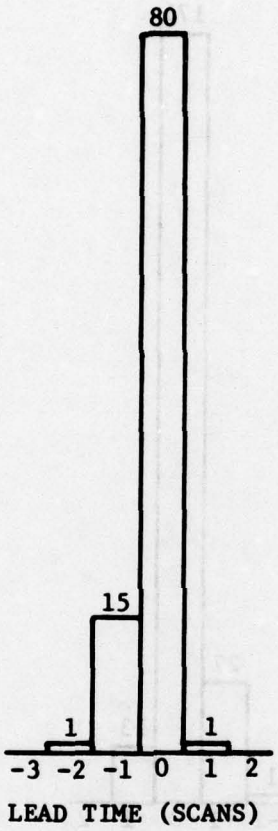


FIGURE D-3-4
HISTOGRAM OF LEAD TIMES FOR SIMULATION FILE A100250

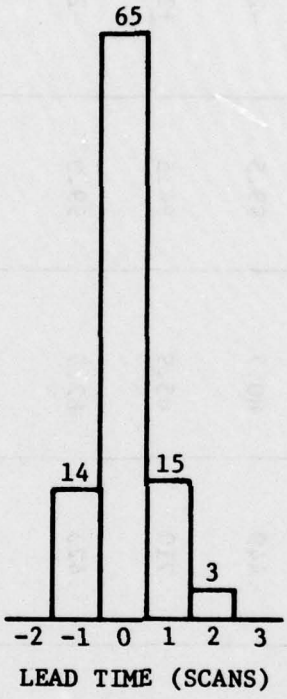


FIGURE D-3-5
HISTOGRAM OF LEAD TIMES FOR SIMULATIOAN FILE A250100

TABLE D-3-1

SIMULATION RESULTS FOR CONFLICT ALERT EMULATOR

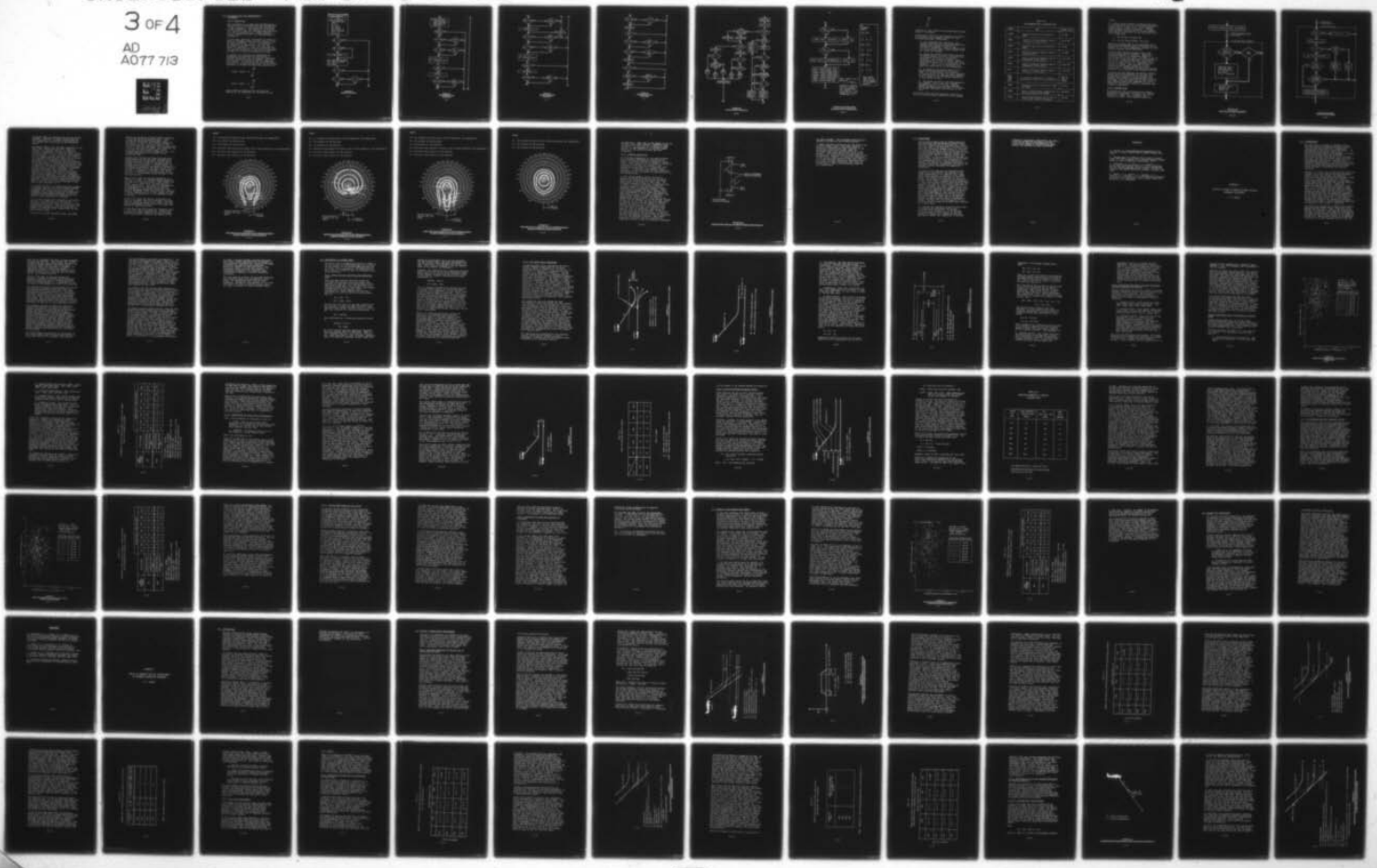
FILE	TOTAL ENCOUNTERS	MEAN LEAD TIME (SCANS)	STANDARD DEVIATION (SCANS)	PERCENT WITH ZERO LEAD TIME	PERCENT WITHIN ±1 SCAN	WORST LEAD TIME (SCANS)
A100100	220	-.075	.449	80.7	99.5	-2
A250250	220	+.032	.710	65.9	94.5	±2
A100250	100	-.165	.423	82.5	99.0	-2
A250100	100	+.072	.646	67.0	96.9	+2
ALL FILES	640	-.029	.586	73.6	97.3	±2

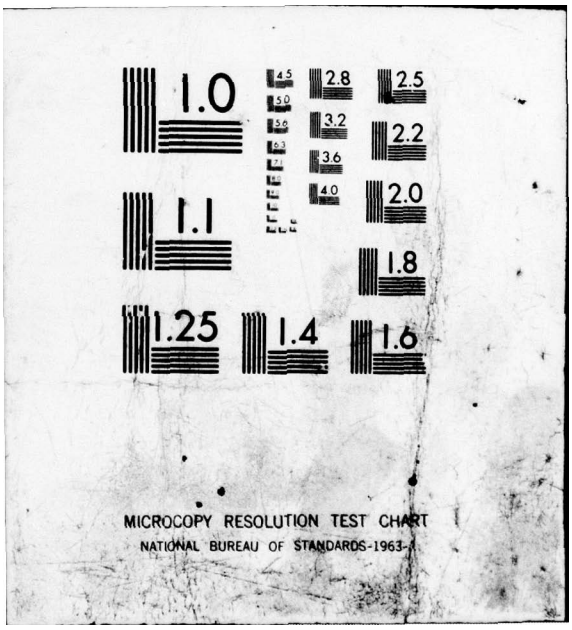
As Table D-3-1 shows, the emulator issued a warning within one scan of Conflict Alert in 97.3% of all cases. The two algorithms were never more than two scans apart. The standard deviation of the lead time was less than 0.6 scan. There were a few simulated encounters (14) which elicited no warning from either algorithm. However, in every case where a warning was given, it was given by both algorithms.

On the basis of these simulations it is concluded that the horizontal portion of the Conflict Alert emulator closely matches the behavior of Conflict Alert. Verification of the vertical portion of the logic has not yet been conducted.

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REPORT OF THE FAA TASK FORCE ON AIRCRAFT SEPARATION ASSURANCE. --ETC(U
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UNCLASSIFIED FAA-EM-78-19-VOL-3 NL

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5.0
5.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

D-4. NEW ATARS LOGIC FOR GENERATION OF ADVISORIES

D-4.1 Description

Once the emulator was operating satisfactorily, a modification of the ATARS logic was incorporated to use a variable tau threshold for IFR/IFR and VFR/VFR encounters. The flowcharts of Figures D-4-1 and D-4-2 show the detection logic for ATARS with the new modifications. These flowcharts replace Figures 5-17 and 5-16, respectively, of Reference 3.

The new logic generates thresholds for advisories which are closely related, within limits, to the emulator thresholds. To make this possible, it was necessary to use separate vertical and horizontal thresholds. Thus, for each type of alert, TV (vertical tau) and TH (horizontal tau) are compared separately to appropriate thresholds instead of to a single threshold, as before.

In general, the vertical and horizontal tau thresholds are calculated by subtracting a constant difference from the emulator thresholds and limiting the results by constant upper and lower bounds. For instance, the tau thresholds for positive or negative advisories for an IFR/IFR encounter in terminal airspace are calculated as:

$$TIFRV = TCONV - 35 \Big\lceil_{20}^{30}$$

$$TIFRH = TCONH - 35 \Big\lceil_{20}^{30}$$

where TCONV and TCONH are the vertical and horizontal tau thresholds for the emulator and

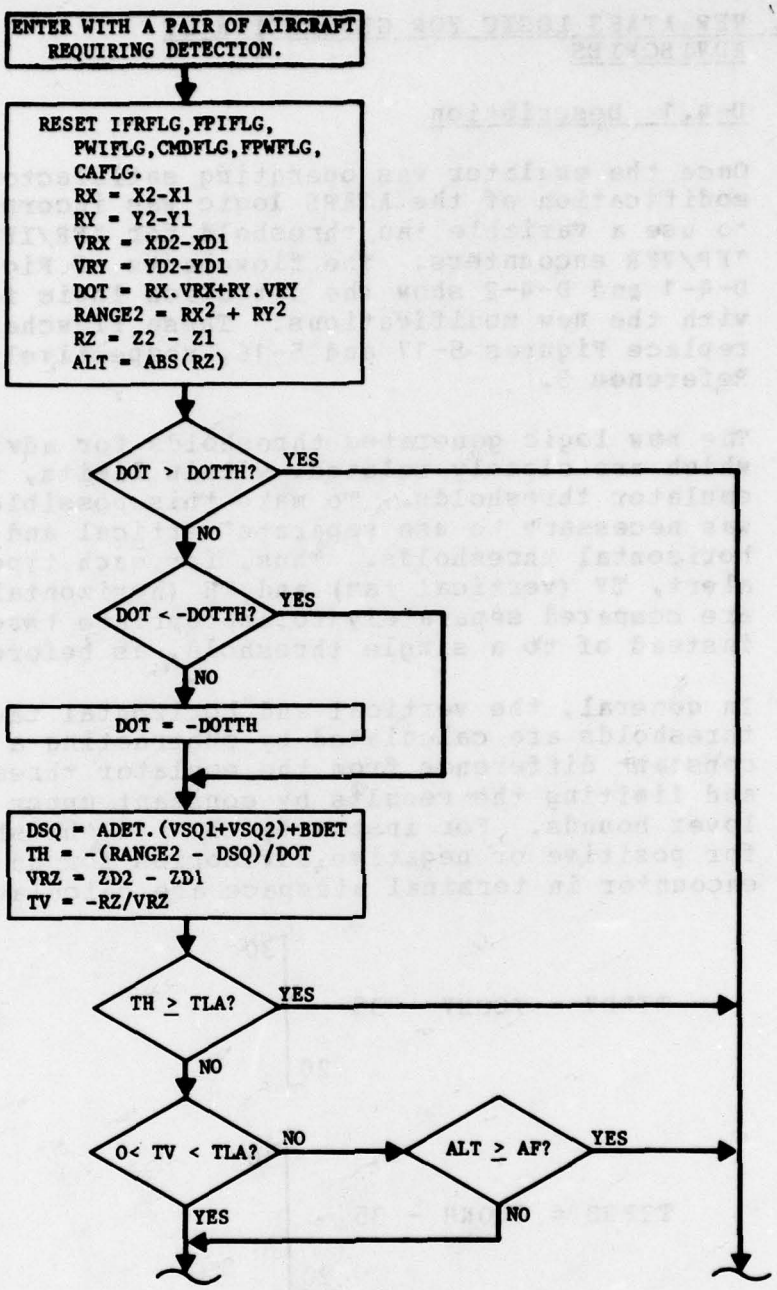


FIGURE D-4-1
NEW DETECTION LOGIC

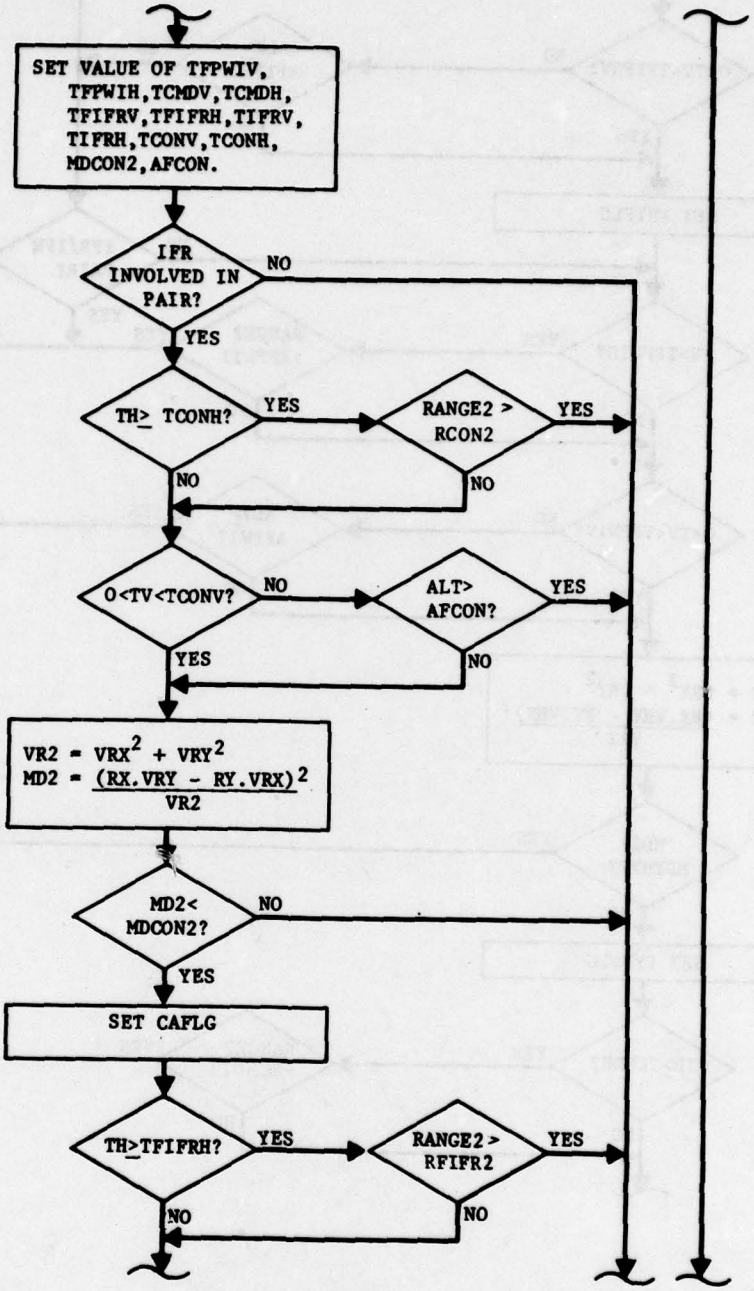


FIGURE D-4-1
NEW DETECTION LOGIC
(CONTINUED)

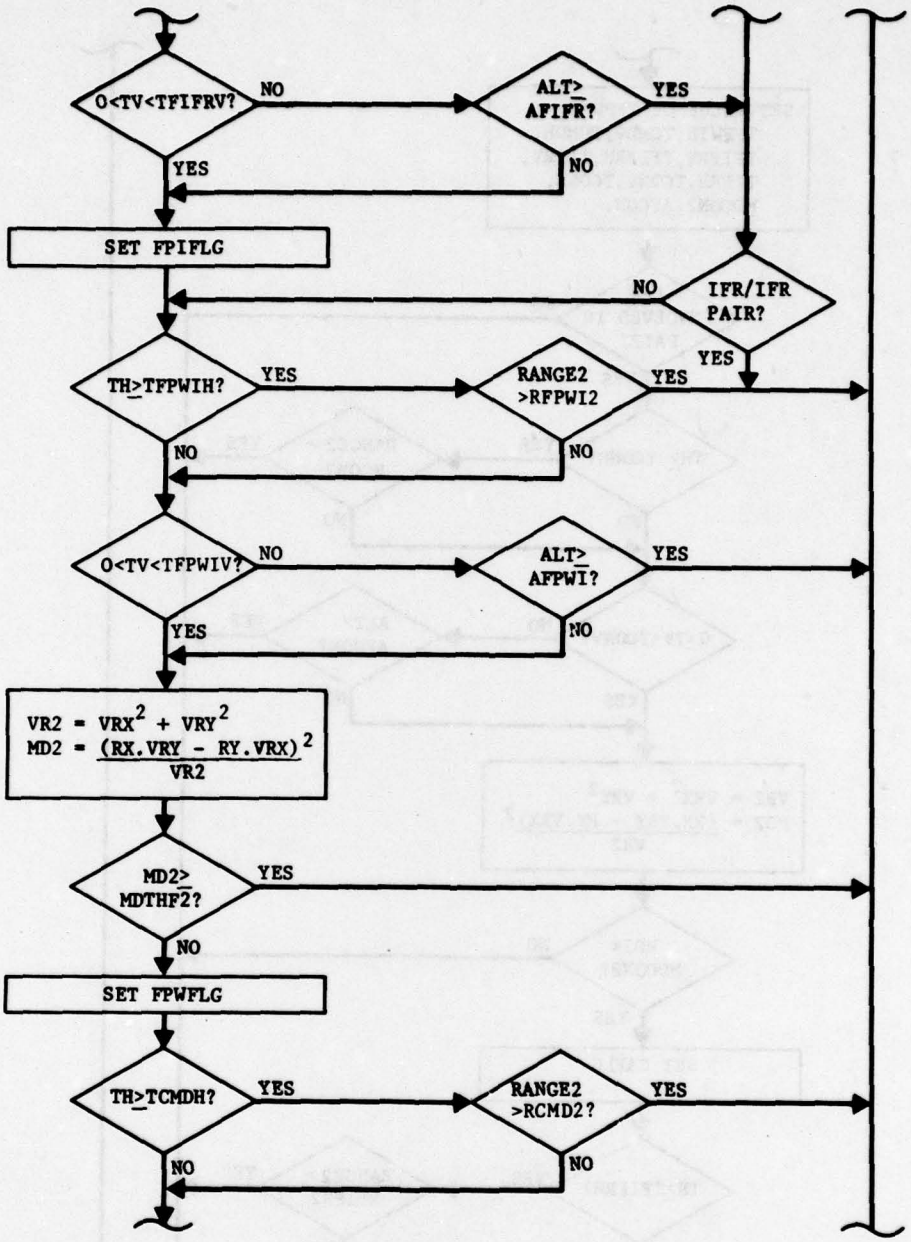


FIGURE D-4-1
NEW DETECTION LOGIC
(CONTINUED)

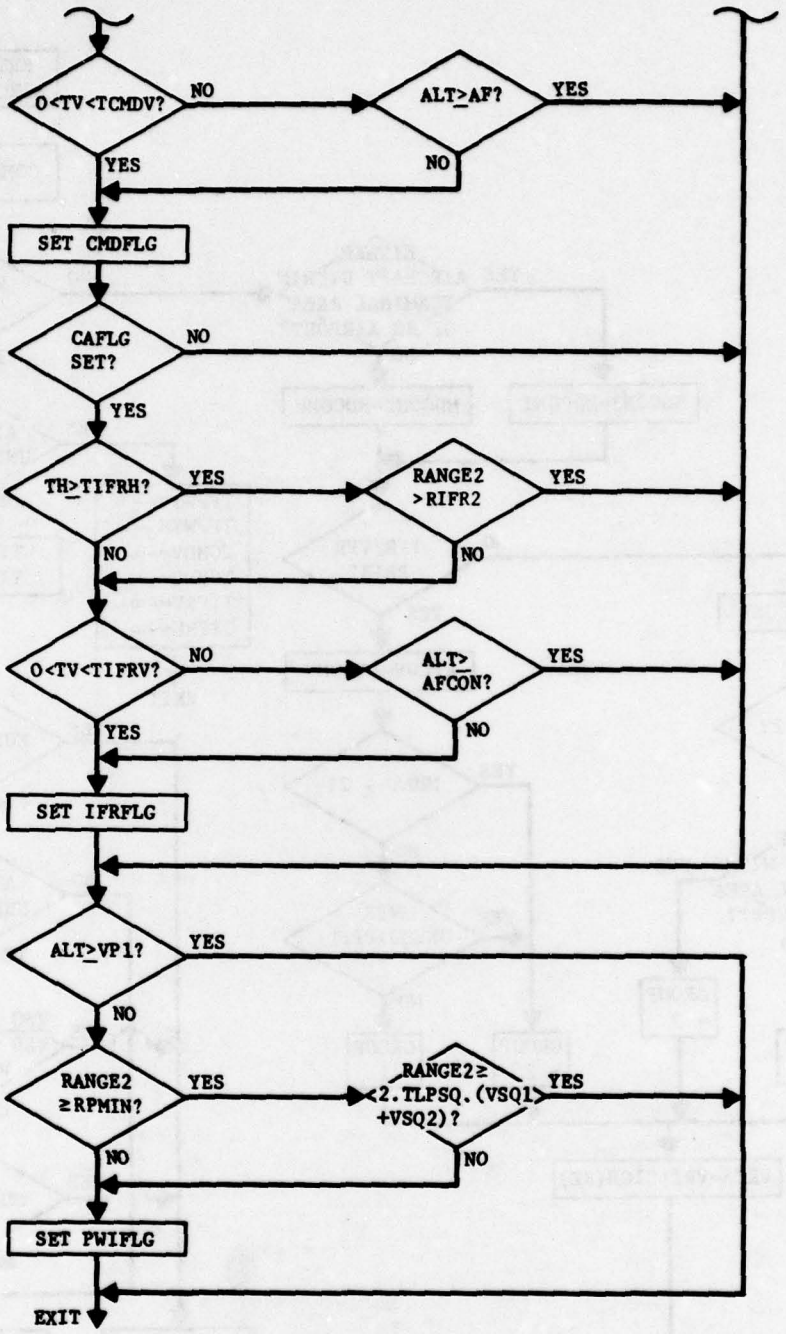


FIGURE D-4-1
NEW DETECTION LOGIC
(CONCLUDED)

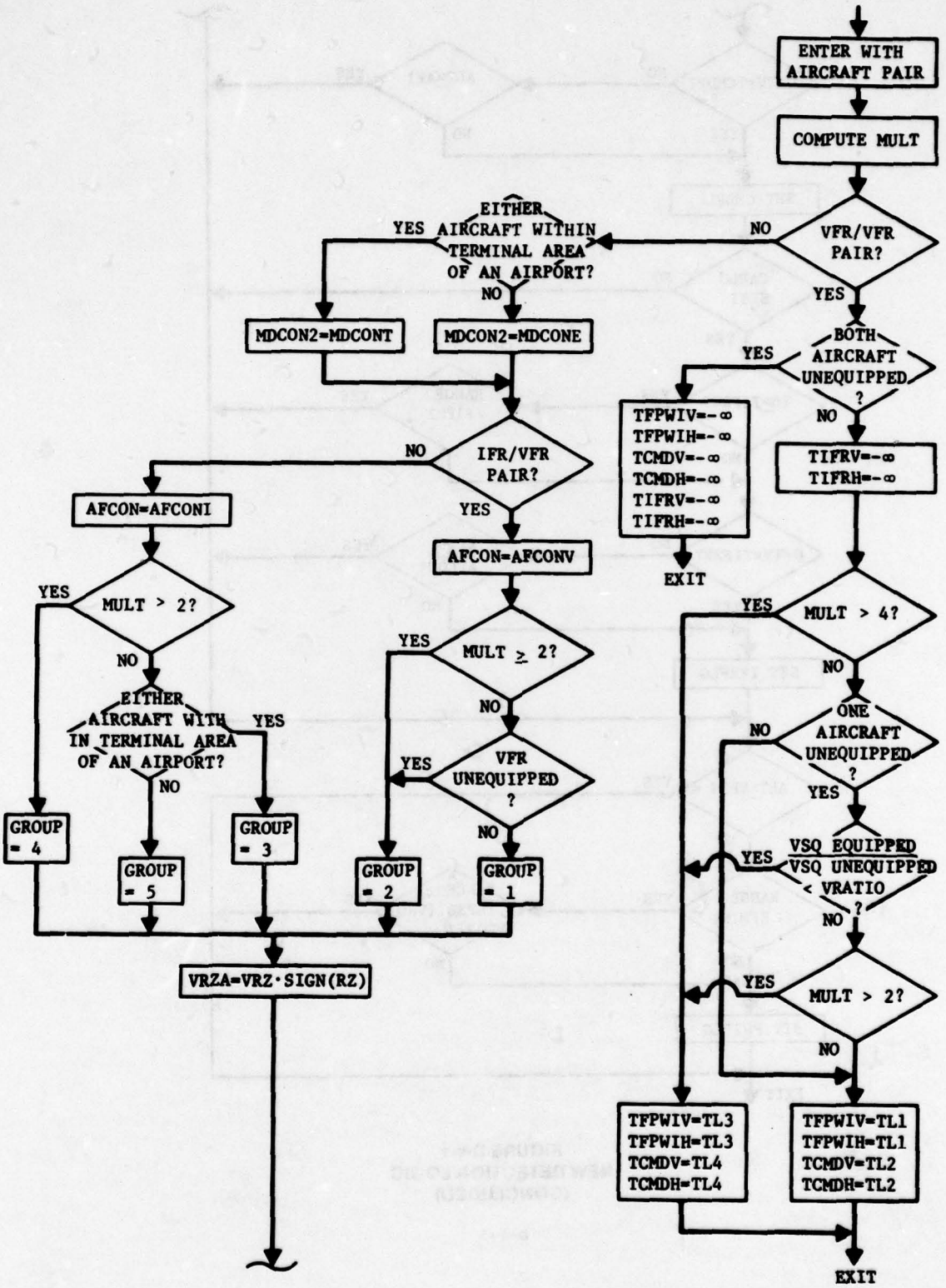
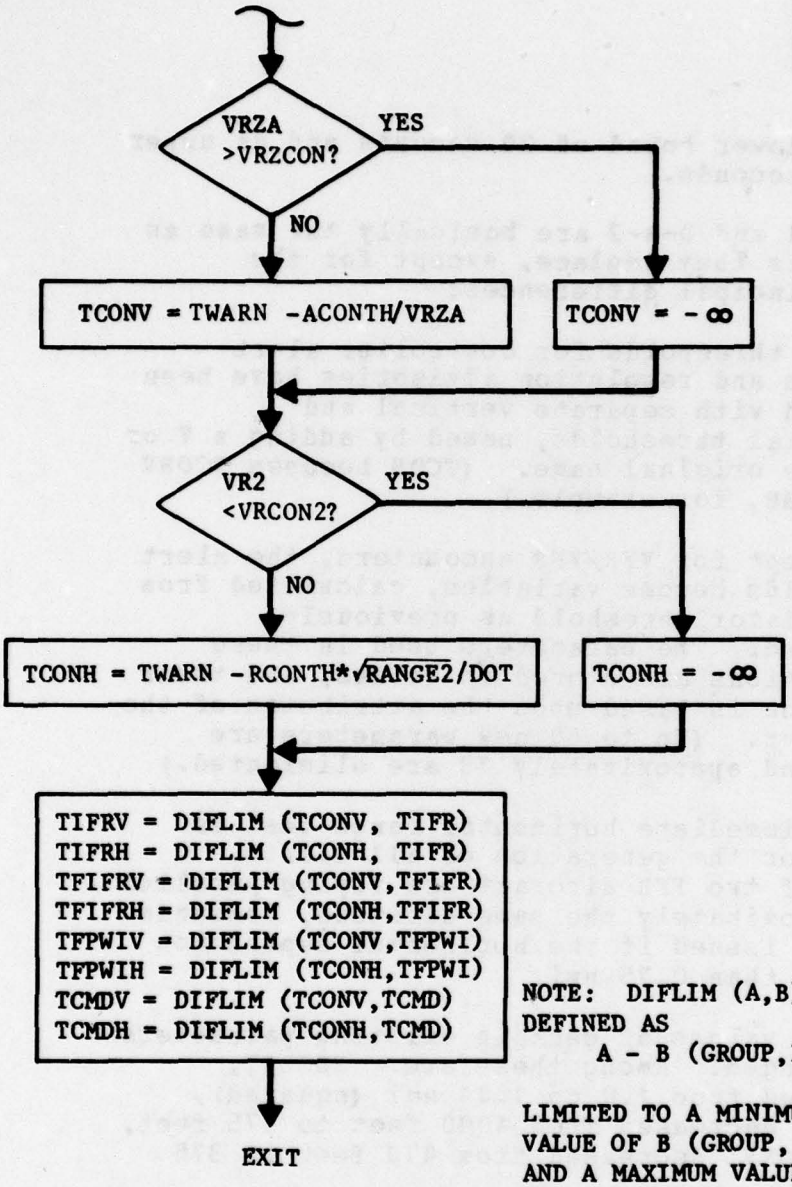


FIGURE D-4-2
CALCULATION OF THRESHOLDS



NOTE: DIFLIM (A,B) IS DEFINED AS

A - B (GROUP,1),

LIMITED TO A MINIMUM VALUE OF B (GROUP, 2) AND A MAXIMUM VALUE OF B (GROUP,3). B IS ASSUMED TO BE A TABLE DIMENSIONED (5,3).

NEW PARAMETER TABLES:

TIFR (5X3):

-	-	-
-	-	-
35.	20.	30.
-	-	-
-	-	-

TFIFR (5X3):

-	-	-
-	-	-
20.	35.	45.
-	-	-
-	-	-

TFPWI (5X3):

-	-	-
-	-	-
20.	35.	45.
-	-	-
-	-	-

TCMD (5X3):

-	-	-
-	-	-
35.	20.	30.
-	-	-
-	-	-

NOTE: VALUES SHOWN ARE FOR IFR/IFR ENCOUNTERS IN TERMINAL AIRSPACE

FIGURE D-4-2 (CONCLUDED)
CALCULATION OF THRESHOLDS



indicates a lower bound of 20 seconds and an upper bound of 30 seconds.

Figures D-4-1 and D-4-2 are basically the same as the flowcharts they replace, except for the following principal differences:

a) The thresholds for controller alert warnings and resolution advisories have been replaced with separate vertical and horizontal thresholds, named by adding a V or H to the original name. (TCON becomes TCONV and TCONH, for example.)

b) Except for VFR/VFR encounters, the alert thresholds become variables, calculated from the emulator threshold as previously explained. The parameters used in these calculations are stored in tables, and their selection is based upon the attributes of the encounter. (Up to 60 new parameters are added and approximately 13 are eliminated.)

c) An immediate horizontal range test is added for the generation of all alerts. Thus, if two IFR aircraft are flying parallel at approximately the same altitude, commands will be issued if the horizontal separation is less than 0.75 nmi.

d) The values of certain existing parameters are changed. Among these are: MDCONT, increased from 1.0 to 1.44 nmi (squared), AFCONI, decreased from 1000 feet to 375 feet, and AFCONV, decreased from 470 feet to 375 feet.

Table D-4-1 lists the new parameters required by the new detection logic, along with their nominal

TABLE D-4-1

NEW PARAMETERS USED IN DETECTION LOGIC

SYMBOL	USE	NOMINAL VALUE
ACONTH	Vertical range used in calculation of TCONV.	375 FEET
RCMD2	Square of horizontal immediate range for advisories to a VFR aircraft.	0.5625 NMI^2
RCONTH	Horizontal range used in calculation of TCONH.	1.2 NMI
RCON2	Square of horizontal immediate range for controller alert.	1.44 NMI^2
RFIFR2	Square of horizontal immediate range for a flashing PWI to IFR aircraft.	0.5625 NMI^2
RFPWI2	Square of horizontal immediate range for a flashing PWI to VFR aircraft.	0.5625 NMI^2
RIFR2	Square of horizontal immediate range for advisories to IFR aircraft.	0.5625 NMI^2
TCMD TFIFR TFPWI TIFR	5 X 3 tables of values used to calculate thresholds for advisories and flashing PWI's.	(see last page of Figure D-4-2).
TWARN	Warning time used in calculation of TCONV and TCONH.	36.8 SEC
VRCON2	Square of relative speed threshold used to test for horizontal slow closing.	3528 $KNOT^2$
VRZCON	Relative speed threshold used to test for vertical slow closing or divergence.	-300 FPM

values.

The Conflict Alert emulator sliding-window logic is implemented in the controller alert processing module shown in Figure D-4-3. This flowchart replaces Figure 5-28 in Reference 3. The new logic requires the addition of two new items of information to each entry in the controller alert list. These are:

1) the integer variable NCA

2) the bit-string WINSTR (10 bits).

Adding the variable NCA to the controller alert list ensures controller alert processing for each conflict at its first appearance, as well as every NCATH processing cycles thereafter.

The bit-string WINSTR represents the actual sliding window for each conflct. Each time a particular conflict is processed, WINSTR is shifted one bit to the right. If CAFLG is set for the conflict, then the left-most bit of WINSTR is set to '1'. If MCTA of the first NCTA bits in WINSTR are found to be '1', a controller alert message is issued. MCTA and NCTA are new parameters with nominal values of 3 and 5, respectively. The maximum possible value of each parameter is 10, limited by the length of WINSTR.

Provision has been made for the emulator sliding window logic to be bypassed in the event that advisories are issued to an IFR aircraft in a conflict pair before the sliding-window logic is satisfied. This provision and the use of NCA for each conflict ensure that commands will not be issued for IFR aircraft before a controller alert message is generated.

D-4.2 IFR/VFR Logic

The calculation of tau thresholds for IFR/VFR encounters is basically the same as for IFR/IFR encounters, except that a different set of constants is used. This normally results in

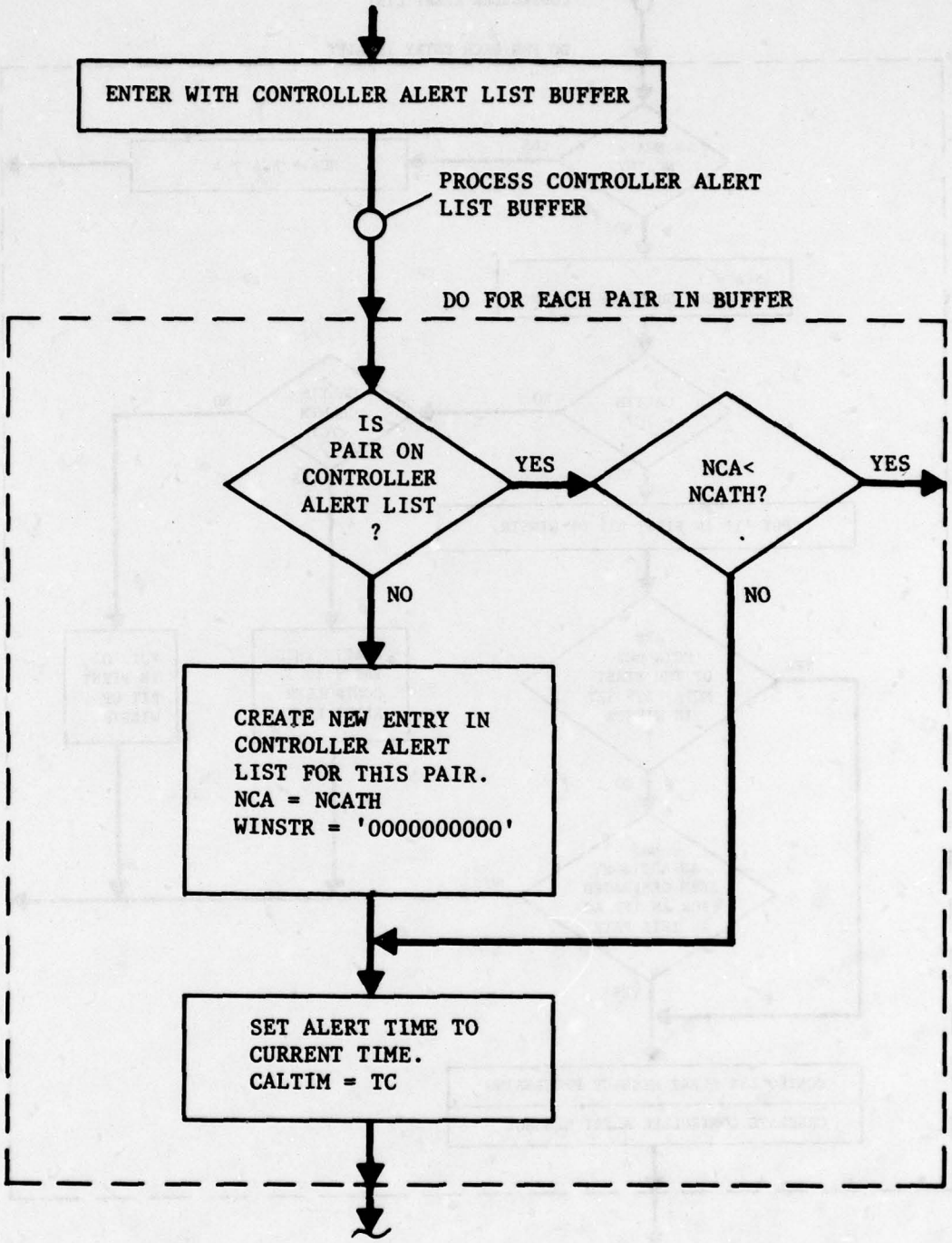


FIGURE D-4-3
CONTROLLER ALERT PROCESSING

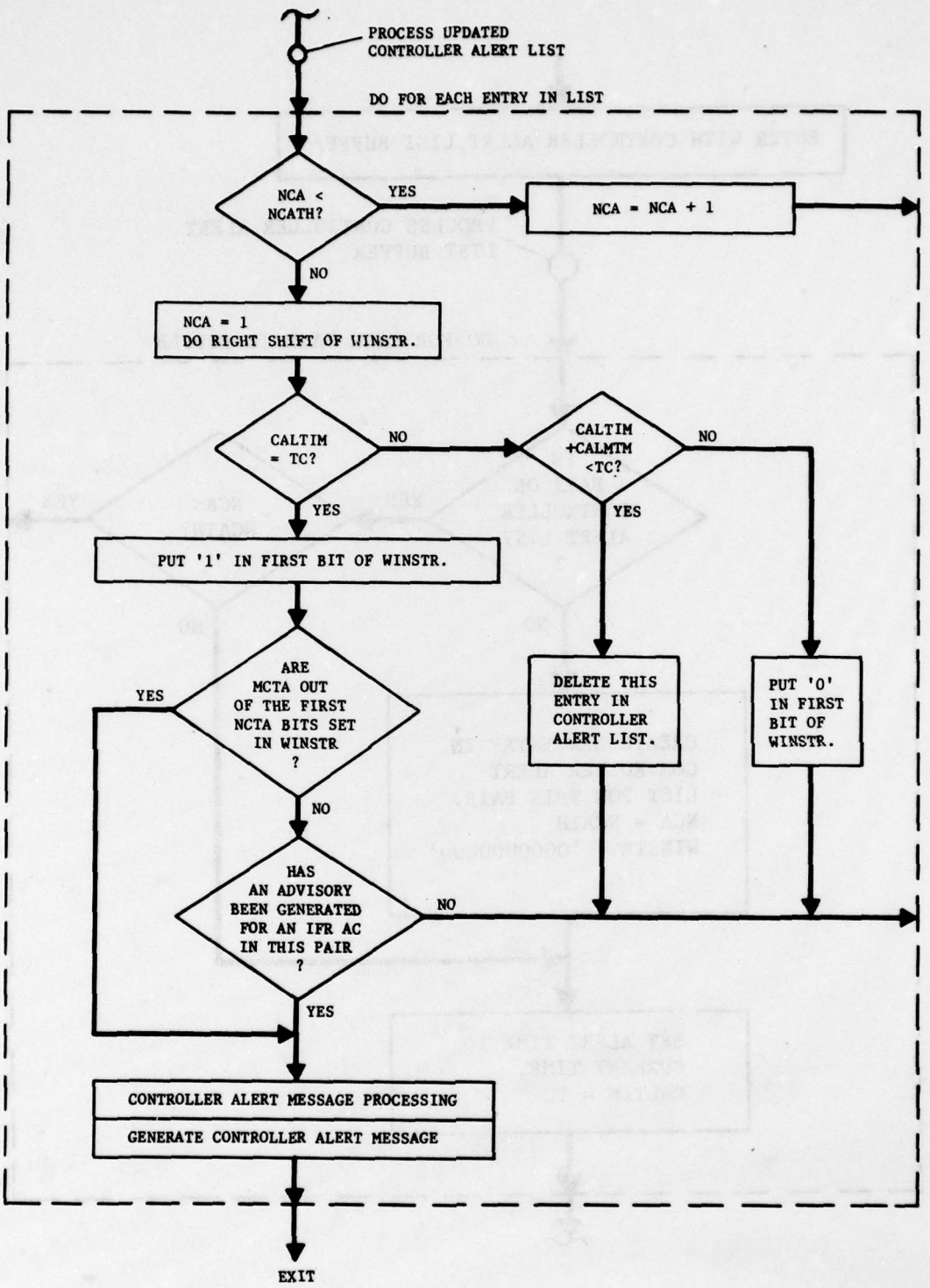


FIGURE D-4-3 (CONCLUDED)
CONTROLLER ALERT PROCESSING

thresholds that are different for the IFR and VFR aircraft. Although the exact details have not been finalized, it is presently envisioned that the IFR/VFR logic would work in the following manner:

The values taken by the variable thresholds in the ATARS logic depend upon the total number of aircraft in a conflict cluster. A conflict cluster is composed of all aircraft which are in pairwise conflict with at least one other aircraft in the cluster. If both aircraft in an IFR/VFR pair are ATARS-equipped (and fewer than 4 aircraft are involved in the conflict cluster), the controller alert threshold and the threshold for advisories to the IFR aircraft would be calculated in the same manner as for IFR/IFR encounters. The threshold for VFR advisories would be calculated by subtracting a constant (nominally 15 seconds) from the controller alert threshold. The immediate horizontal range for VFR advisories would be set to some fixed value to accomodate slow-closing encounters. This value (nominally 1 mile) would be intermediate between the immediate thresholds for IFR advisories and controller alert warnings. Flashing Proximity Warning Indicators (PWI's) would be issued to both aircraft at the time of the controller alert.

If the VFR aircraft is equipped only with a Mode-C Air Traffic Control Radar Beacon System (ATCRBS) transponder (and fewer than 4 aircraft are involved), the controller alert and flashing PWI thresholds would remain unchanged, but the tau threshold for IFR advisories would be set to a constant value (nominally 30 seconds).

If 4 or more aircraft are involved in an IFR/VFR conflict, the thresholds for IFR and VFR advisories would be increased to a constant value (nominally 60 seconds). The controller alert and flashing PWI thresholds would be calculated as before, but would be given a lower limit of this same constant value.

In each of the cases described above, any ATARS

advisories for either aircraft would be selected at the time of the controller alert. This information would then be provided to the controller, in concert with Conflict Resolution advisories, so that any action taken by the controller would be compatible with the advisories issued to the pilots by ATARS. Once selected, the advisories for both aircraft would remain unchanged for some minimum period of time. This requires modification of the ATARS master resolution logic.

Figures D-4-4 through D-4-7 are time and range plots showing the various ATARS thresholds for IFR/VFR collision encounters at various speeds. Straight and level flight at constant speed is assumed for each aircraft. In each figure, the plotted angle represents the angle of incidence of the flight paths and not the true bearing of one aircraft in relation to the other. The slower aircraft is assumed to be in the center of each plot, but it is irrelevant which aircraft is IFR and which if VFR.

Figure D-4-4 shows the various thresholds as a function of time. The radial distance represents the true time before collision. The aircraft are assumed to be traveling at 150 knots and 200 knots, respectively. Note that for approximately a 22-degree sector at the bottom of the plot (corresponding to an overtake situation), the emulator parameter VRCON2 (representing a relative velocity threshold of 59.4 knots) causes the logic to switch discontinuously to the immediate range thresholds.

Figure D-4-5 shows the various thresholds as a function of range. The plot represents the same aircraft speeds as Figure D-4-4, except that the separation distance is plotted on the radial axis instead of time-to-collision.

Figures D-4-6 and D-4-7 show true threshold times for two other speed combinations. Figure D-4-6 represents aircraft speeds of 150 and 180 knots, while Figure D-4-7 is plotted for speeds of 100

LEGEND:

T/C - Tau threshold for Conflict Alert, Conflict Resolution, and flashing PWI's

T/V - Tau threshold for VFR advisories

T/I - Tau threshold for IFR advisories

R/C - Horizontal range threshold for Conflict Alert, Conflict Resolution, and flashing PWI's

R/V - Horizontal range threshold for VFR advisories

R/I - Horizontal range threshold for IFR advisories

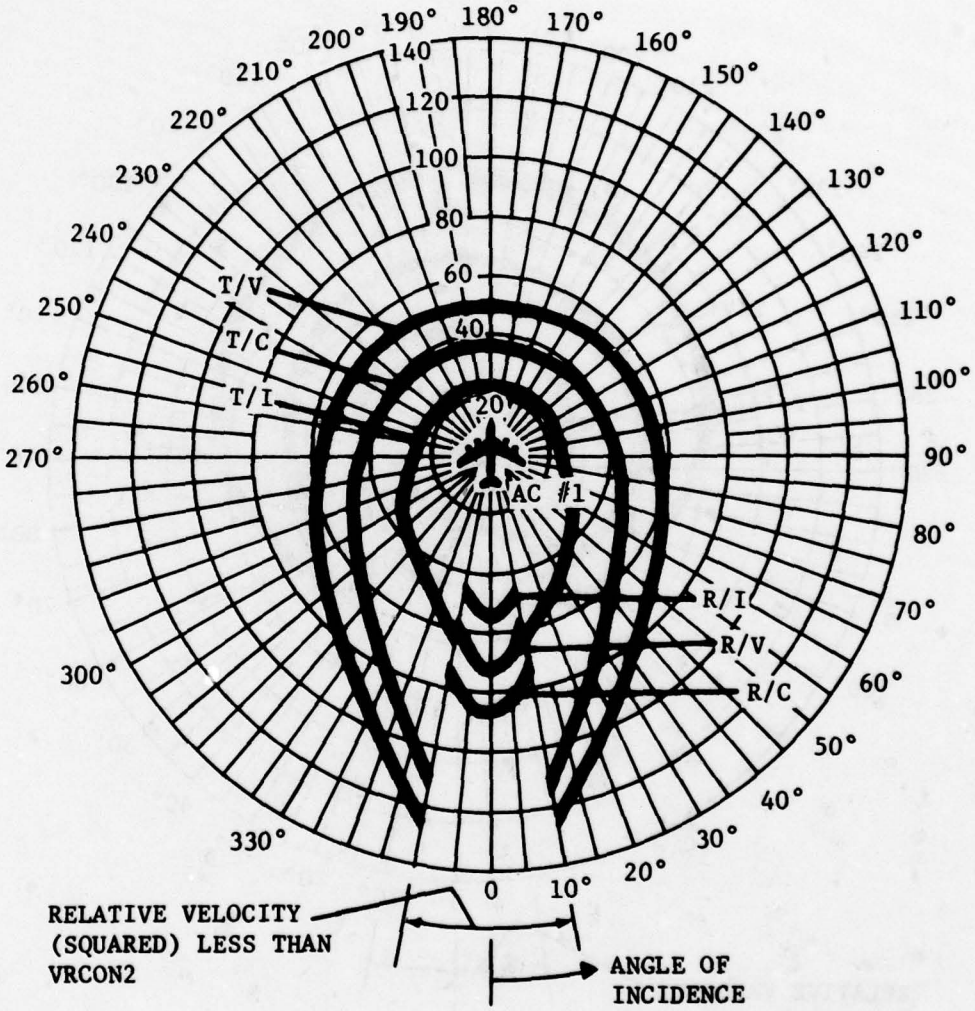


FIGURE D-4-4
TRUE TIME-TO-COLLISION FOR IFR/VFR THRESHOLDS WITH AIRCRAFT SPEEDS OF 150 AND 200 KNOTS

LEGEND:

T/C - Tau threshold for Conflict Alert, Conflict Resolution, and flashing PWI's

T/V - Tau threshold for VFR advisories

T/I - Tau threshold for IFR advisories

R/C - Horizontal range threshold for Conflict Alert, Conflict Resolution, and flashing PWI's

R/V - Horizontal range threshold for VFR advisories

R/I - Horizontal range threshold for IFR advisories

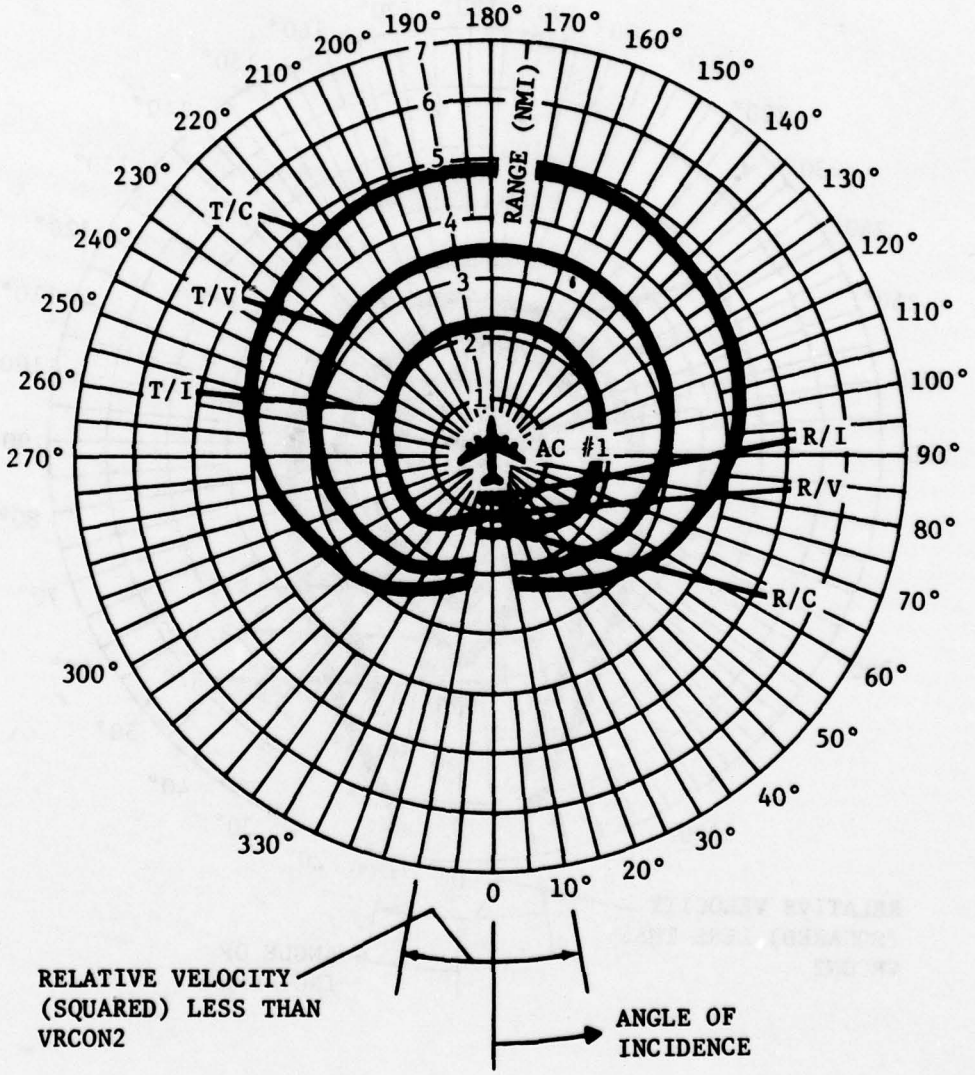


FIGURE D-4-5
SEPARATION DISTANCES FOR IFR/VFR THRESHOLDS WITH AIRCRAFT SPEEDS OF 150 AND 200 KNOTS

LEGEND:

T/C - Tau threshold for Conflict Alert, Conflict Resolution, and flashing PWI's

T/V - Tau threshold for VFR advisories

T/I - Tau threshold for IFR advisories

R/C - Horizontal range threshold for Conflict Alert, Conflict Resolution, and flashing PWI's

R/V - Horizontal range threshold for VFR advisories

R/I - Horizontal range threshold for IFR advisories

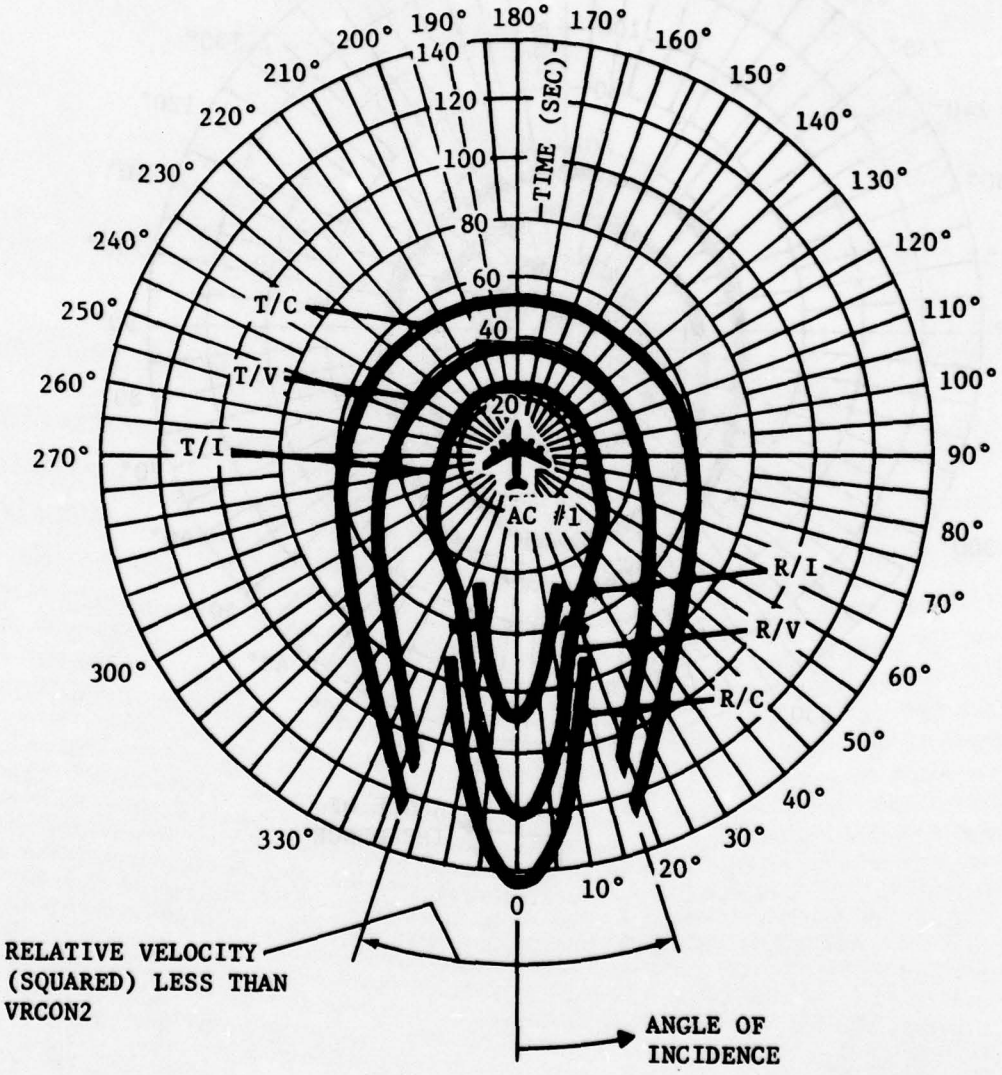


FIGURE D-4-6

TRUE TIME-TO-COLLISION FOR IFR/VFR THRESHOLDS WITH AIRCRAFT SPEEDS OF 150 AND 180 KNOTS

LEGEND:

T/C - Tau threshold for Conflict Alert, Conflict Resolution, and flashing PWI's

T/V - Tau threshold for VFR advisories

T/I - Tau threshold for IFR advisories

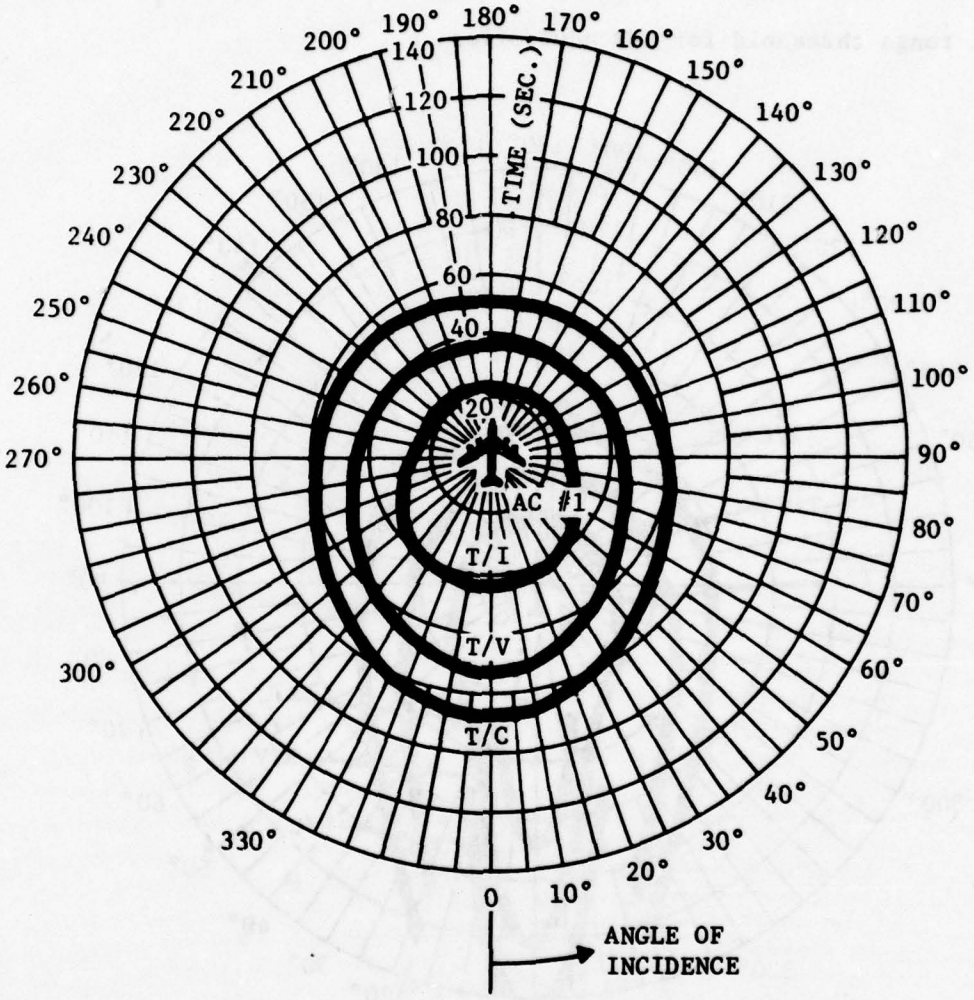


FIGURE D-4-7
TRUE TIME-TO-COLLISION FOR IFR/VFR THRESHOLDS WITH AIRCRAFT SPEEDS OF 100 AND 200 KNOTS

and 200 knots. Note that as the speeds of the two aircraft come closer together, immediate range thresholds are used over an increasingly wider sector. As the difference in aircraft speeds increases, this sector narrows, and then disappears.

D-4.3 Conflict Resolution

An additional requirement of the ATARS-Conflict Alert interface development activity was to provide a Conflict Resolution capability within ATARS. This capability was to provide a family of suggested resolutions for display to the controller at the time that a controller alert warning was generated by the Conflict Alert emulator. It was found that Conflict Resolution advisories could be provided for the controller in the following way.

At the time of Conflict Alert, the master resolution module of ATARS would be called to generate the resolution advisories that ATARS would issue to the pilots at that point. If horizonal advisories (positive or negative) were to result, a family of possible resolution maneuvers based on these advisories would be presented on the controller's display. Figure D-4-8 shows an example of such a display for a head-on encounter in which ATARS had generated turn right (or don't turn left) advisories. The dashed lines indicate a range of possible maneuvers for each aircraft. One edge of the family could be selected to be the current tracked heading of the aircraft and the other edge could be selected to be a certain number of degrees (perhaps 60 degrees) in the direction of the ATARS-generated advisory. The straight-ahead direction would be permitted, because in any specific case the controller could choose to maneuver only one of the aircraft. It would be the responsibility of the controller to select a specific instruction for one or both of the pilots from the two families presented. When ATARS generates a vertical advisory (positive or negative) an up or a down arrow would be displayed

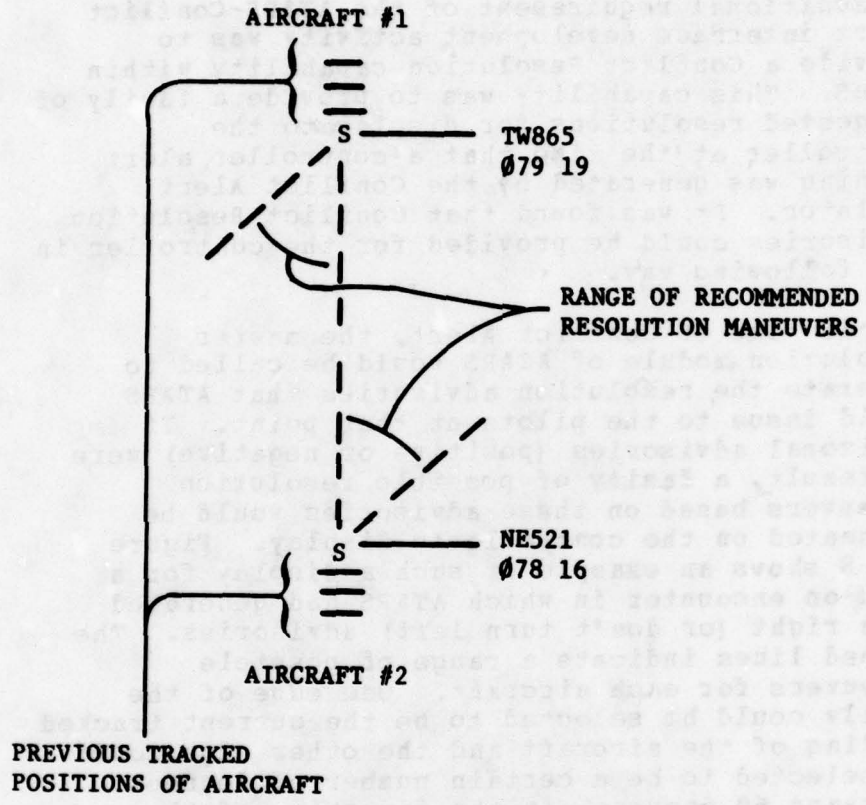


FIGURE D-4-8
CONTROLLER'S DISPLAY OF CONFLICT RESOLUTION ADVISORY

for each aircraft. The controller would select a specific altitude for one or both aircraft.

If ATARS resolution advisories for the pilots were required within a short time after Conflict Resolution advisories had been displayed to the controller, ATARS would simply issue the advisories previously selected directly to the aircraft. This would ensure that instructions issued by the controller and by ATARS would not be incompatible. However, if resolution advisories to the aircraft were required later than about six scans after Conflict Resolution advisories were displayed, the ATARS resolution logic would be called again to see if new advisories would be more appropriate.

D-5. CONCLUSIONS

The results of exercising the ATARS resolution advisory logic and the Terminal Conflict Alert logic with eight hours of recorded live traffic data show that it is difficult to achieve a fixed real-time difference between alerts by adjusting the threshold values of the two alerting logics. In these studies, where about +20 seconds of real-time difference would be expected, actual time differences of -14, 0, 3, and 28 seconds were experienced. It was not possible to overcome all factors which contribute to a dispersion of alert time differences (e.g., turning encounters). However, the results did indicate differences in the logics which were responsible for some of the observed scatter and which were amenable to correction.

A Conflict Alert emulator was developed which conveniently incorporated the essence of the linear prediction of the Conflict Alert logic, while making minimum disturbance to the ATARS logic. The results obtained thus far with the Conflict Alert emulator indicate the feasibility of this approach for producing results comparable to those from Conflict Alert within ATARS and make possible the shift of this function from ARTS to ATARS. In making this shift, adaptation of site-specific data describing the Conflict Alert area types would be required for ATARS. The emulator algorithm programmed for this investigation is admittedly much simpler than the full Conflict Alert algorithm and might have to be made more complex in order to cover all of the special situations which Conflict Alert is designed to handle. Further tests and refinements of the emulator should be made using additional recorded air traffic data.

The variable tau threshold detection logic does, of course, need additional testing and optimization of parameters. To provide an important input in this regard, an existing program for Monte Carlo simulation has been modified to permit the simulation of aircraft

response to controller instructions, so that a study can be made of the degree to which instructions issued by the controller might prevent the issuance of ATARS advisories.

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1. Jolitz, G., "ATC/Airborne CAS Compatibility-An Analysis of Field Derived Data", FAA-RD-75-228, June, 1976.

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3. McParland, A. L., Patel, K. R., Roberts, D. L., "Multi-Site Intermittent Positive Control Algorithms for the Discrete Address Beacon System", FAA-EM-74-4, Change 2, The MITRE Corporation, McLean, Virginia, May, 1976.

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APPENDIX E

ABILITY OF ATARS TO PROTECT AGAINST ALTITUDE CLEARANCE VIOLATIONS

A. D. Mundra

E-1. INTRODUCTION

The statistics in Volume II relating to the aircraft separation assurance problem indicate that altitude deviations are a significant contributor to the mid-air collision threat. An altitude deviation occurs when a pilot significantly overshoots or undershoots his level-off to an assigned altitude or departs significantly from level flight at an assigned altitude. Altitude deviations often occur due to high workload, distraction, inattention, or misunderstood clearances. A natural role for an automatic separation assurance system would be to issue resolution advisories when an altitude deviation leads to the threat of a mid-air collision.

However, the separation assurance system cannot be designed to protect against altitude deviations without taking into account the operating practices used within the National Airspace System today. In normal operations, air traffic controllers may issue clearances to Instrument Flight Rules (IFR) aircraft that provide 1000 feet separation between aircraft. (2000 feet separation must be provided above Flight Level 290.) If a descending aircraft makes a normal level-off at a cleared altitude 1000 feet above another aircraft (with the two aircraft in close horizontal proximity), the separation assurance system should not require resolution maneuvers. On the other hand, if a pilot or controller error should occur which results in a true conflict between two aircraft, the separation assurance system must be able to issue resolution advisories in sufficient time to avert a collision.

Controllers are permitted to separate an aircraft operating under Visual Flight Rules (VFR) from another VFR aircraft or from an IFR aircraft by 500 feet in altitude. The rules for establishing cruising altitudes below 18,000 feet also make it possible for IFR and VFR aircraft to be separated by 500 feet. (VFR aircraft flying in an easterly direction fly at odd thousands of feet plus 500

feet and in a westerly direction at even thousands of feet plus 500 feet. IFR aircraft fly at odd thousands of feet when flying toward the east and at even thousands of feet toward the west.) Therefore, when a VFR aircraft is involved, the separation assurance system must permit a descending aircraft to level-off 500 feet above another aircraft, yet it must be able to protect against an altitude deviation.

Clearly, the goals of avoiding unnecessary intrusion in normal situations and of providing adequate separation when an altitude deviation occurs are competing goals. A compromise in the two types of performance will have to be accepted.

The presence of altimetry errors makes the task of discriminating between normal level-offs and altitude deviations more difficult. With some combinations of altimetry errors, the separation assurance system will think the aircraft closer than they really are and will issue unnecessary advisories. With other combinations of errors, the aircraft will be closer than indicated and the separation assurance system will be late in giving advisories or may fail to give advisories at all.

This appendix contains analysis and simulation results that indicate the degree to which an automatic separation assurance system can protect against altitude deviations while avoiding unnecessary alerts. The separation assurance system considered here is the Automated Traffic Advisory and Resolution Service (ATARS) formerly known as Intermittent Positive Control (IPC). Although the analysis has been carried out for ATARS, many of the results also apply to other separation assurance systems, namely Conflict Alert and the Beacon Collision Avoidance System (BCAS). Specific recommendations for changes to ATARS parameters are made based upon the results of this study.

This study began by evaluating the performance of the current ATARS algorithm when operating with a radar scan period of 4.7 seconds. The version

that was studied is presented in Reference 1. Two indices of performance were used. They are: 1) the ability of ATARS to provide protection when an aircraft with a vertical rate fails to level off, and 2) the unnecessary alerts generated when pilots are following their clearances. Two types of encounters were simulated via Monte Carlo simulation to obtain these indices. They were the broken clearance encounters and the normal level-off encounters. Frequency of surveillance and communication, reliability of surveillance and communication, altimetry errors, vertical tracker performance, and the type of collision avoidance logic are factors that have an impact on these performance indices. These factors were taken into account in this study.

The results with the current ATARS showed that ample protection against altitude deviations could be provided, but very high rates of unnecessary alarms would be experienced. The vertical portion of the ATARS collision avoidance algorithm was then analyzed. This analysis suggested some changes to the logic which determines whether the resolution advisories, when required, should be positive or negative advisories. Changes were developed and tested and an improved balance between the two performance measures was noted.

The Federal Aviation Administration (FAA) has been considering how to deploy the Discrete Address Beacon System (DABS) and ATARS to provide service in en route airspace. If DABS and ATARS were to be incorporated into the existing Air Route Surveillance Radars (ARSR's) they would be forced to operate with radar scan periods of 10 to 12 seconds instead of the 4 to 5 seconds used by terminal radars. A previous study (Reference 2) showed that satisfactory ATARS service could not be provided for VFR operations unless the scan period were shorter than 5 or 6 seconds. However, it has been proposed that ATARS might serve a more limited role in high altitude en route airspace where separations are larger and dependence upon visual sighting of aircraft is not a factor. Thus, it is relevant to also evaluate the ability

of ATARS to protect against altitude deviations when using a radar scan period of 10 seconds. A trial-and-error procedure for adjusting the ATARS parameters was used to obtain acceptable protection against altitude deviations. The unnecessary alarm rate was then observed. A significant increase in the detection time threshold was required to provide acceptable protection.

Only the vertical portions of the ATARS detection and resolution logic were considered in this study. All resolutions were with vertical maneuvers. Throughout this appendix, it is to be understood that the two subject aircraft are at all times in conflict in the horizontal plane.

E-2. PERFORMANCE OF CURRENT ATARS

The first step in studying the ability of ATARS to protect against altitude deviations was to assess the performance of the current ATARS through use of a Monte Carlo simulation. The ATARS vertical detection and resolution logic is reviewed by way of introduction.

E-2.1 ATARS Vertical Detection and Resolution Logic

ATARS performs vertical detection using the altitudes and altitude rates that result from tracking the reported altitudes delivered by the DABS sensor each scan. Let ZT1 and ZT2 be the tracked altitude and ZDT1 and ZDT2 be the tracked altitude rates of two aircraft under consideration. ATARS computes the vertical separation, RZ, and the vertical closing speed, VRZ, by

$$RZ = ZT2 - ZT1$$

$$VRZ = ZDT2 - ZDT1.$$

Vertical tau, TV, which is the time required for the aircraft to reach the same altitude if they maintain their current vertical rates, is used as the time criterion for resolution advisories. It is

$$TV = -RZ/VRZ.$$

The conditions for a resolution advisory are met if

$$ABS(RZ) < AF \text{ or}$$

$$TV < TCMD.$$

AF is the current vertical separation threshold and has a nominal value of 1000 feet. TCMD is a time threshold used as a criterion for vertical tau. TCMD takes one of a set of values, depending upon the attributes (equipage, flight rules, and

speeds of the aircraft, etc.) of the encounter. For the current study, the value appropriate for two VFR aircraft, both equipped with ATARS, was used. This value is referred to as TL2 (nominal value of 32 seconds) in Reference 1.

Normally, the conditions for a resolution advisory must be met on two out of three successive scans before resolution advisories are actually issued to the pilots. However, advisories are issued immediately if:

ABS(RZ) < TAF or

TV < TCMD - TTM.

TAF is a separate threshold for current vertical separation which permits the two-out-of-three requirement to be bypassed. In the current ATARS it has a nominal value of 1000 feet. TTM is a parameter for use with vertical tau which permits the two-out-of-three requirement to be bypassed. It has a nominal value of seven seconds. This bypass is provided so that if an unusually low value of current vertical separation or vertical tau is observed when the conflict conditions are first met (as might happen when one aircraft has just entered ATARS coverage or when a vertical maneuver is suddenly initiated), advisories can be issued immediately.

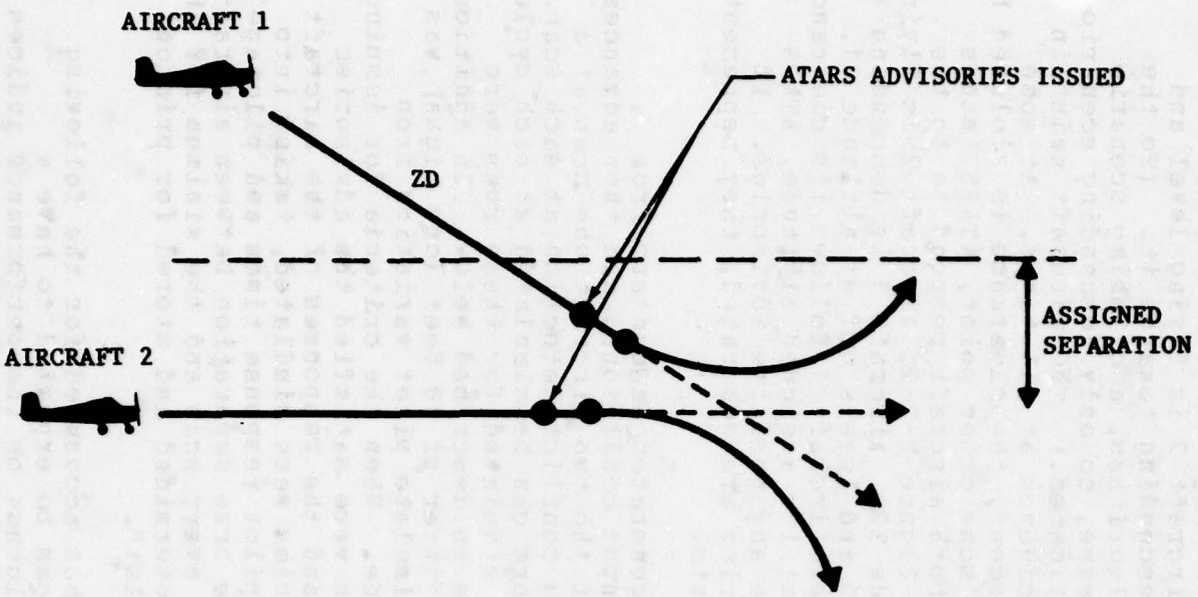
Once it has been determined that resolution advisories are required, ATARS exercises additional logic to determine whether those advisories should be positive advisories (CLIMB/DESCEND) or negative advisories (DON'T CLIMB/DON'T DESCEND). This logic computes a variable called the vertical miss distance, VMD. VMD is a number, greater than or equal to zero, indicating the minimum vertical separation that the two aircraft will have during the next TVPCMD seconds if they maintain constant vertical rates. TVPCMD has a nominal value of 30 seconds. If VMD is less than the parameter ASEPL (nominal value of 470 feet), then positive advisories are required. Negative advisories are required otherwise.

E-2.2 The Monte Carlo Simulation

An existing Monte Carlo simulation was used to conduct computer simulations of the basic scenarios shown in Figures E-2-1 and E-2-2. In Figure E-2-1, Aircraft 2 is flying level and Aircraft 1 is descending towards it. (To the current ATARS algorithms, a climbing scenario would look the same, so only descending scenarios have been investigated.) The aircraft maintain horizontal coincidence at all times. At some point in its descent, the clearance is violated by Aircraft 1. At some other point, ATARS issues advisories and both aircraft respond to to the advisories. In Figure E-2-2, Aircraft 2 is flying level at altitude Z2. Aircraft 1 is descending at vertical rate ZD and levels off at altitude Z1. Ideally, whenever Aircraft 1 follows its clearance and levels off at its assigned altitude, ATARS should not issue any positive advisories. If positive advisories are generated, they represent unnecessary alerts.

The simulation generates encounters from deterministic input conditions, and then advances the positions of the two aircraft one scan at a time, performing conflict detection at each scan. Measurement errors can be simulated at each cycle. The only errors simulated for these runs were altimetry errors as described below. In addition, a scan-to-scan jitter of 10 feet (one sigma) was introduced to simulate pilot variation from assigned altitude. When the criteria for issuing ATARS advisories were satisfied the advisories were selected, and the responses of the aircraft to these advisories were simulated, taking into account random pilot response times and pilotage variations. The true separation between aircraft was computed at every scan and the minimum for the encounter was determined and stored for printout on a "scatter plot".

The simulation has accounted for the following factors, which can be expected to have a significant influence on the performance indices discussed in the preceding section.

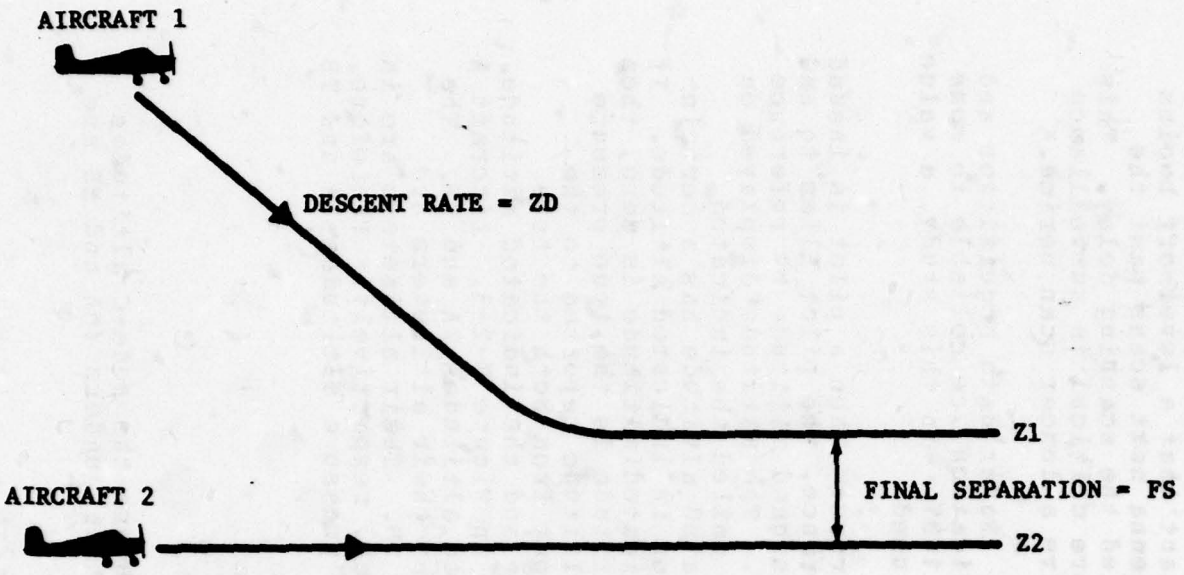


AIRCRAFT 2 IS STRAIGHT AND LEVEL

AIRCRAFT 1 IS DESCENDING AT RATE ZD

HORIZONTAL COINCIDENCE AT ALL TIMES

FIGURE E-2-1
SCENARIO WHEN ALTITUDE CLEARANCE IS NOT FOLLOWED



- PICTURE IS IN VERTICAL PLANE TROUGH FLIGHTS
- FLIGHTS HAVE HORIZONTAL COINCIDENCE AT ALL POINTS

FIGURE E-2-2
SCENARIO WHEN ALTITUDE CLEARANCE IS FOLLOWED

1. Scan Period: The DABS sensor determines the aircraft position once per antenna revolution. In this simulation a scan period of 4.7 seconds was used. This creates an uncertainty in ATARS' knowledge about the position of the aircraft between scans. Thus, the antenna may scan the aircraft at any time within the span of several seconds as it levels off. In this appendix, the time between the instant that a level-off begins and when the antenna next scans past the aircraft is called the scanning delay. This delay becomes more critical in surveillance systems which have a longer scan period.

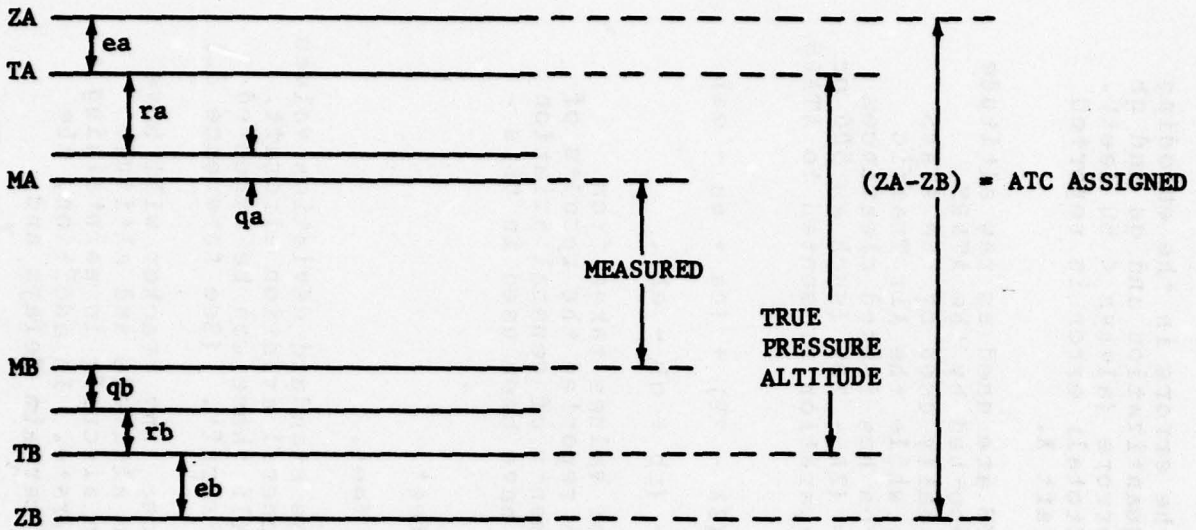
2. Reliability: Radar data acquisition and data link communication are reliable to some value less than 100%. In this study, a value of 96% has been used.

3. Altimetry Errors: When a pilot is issued an altitude clearance, the pilot flies to and maintains the assigned altitude by reference to his altimeter. The altitude displayed on his altimeter is called the indicated altitude. Indicated altitude has a certain error called error in indicated altitude. If the error in indicated altitude is zero, then the indicated altitude is the true pressure altitude. The altitude reported to the ground is different from both the true pressure altitude and the indicated altitude. This is depicted in Figure E-2-3. Aircraft A and B are assigned altitudes ZA and ZB. The altitudes shown by their altimeters are therefore ZA and ZB. Their altimeters are in error by ea and eb, respectively. Therefore, they are at true pressure altitudes TA and TB where:

$$TA = ZA - ea$$

$$TB = ZB - eb.$$

Suppose MA and MB are the Mode-C altitudes reported by the transponders (MA and MB are



ZA, ZB ARE INDICATED (AND HENCE ASSIGNED) ALTITUDES

TA, TB ARE TRUE PRESSURE ALTITUDES

MA, MB ARE REPORTED ALTITUDES

FIGURE E-2-3
DEPICTION OF THE VARIOUS ALTIMETRY ERRORS

quantized to the nearest hundred feet). Then:

$$MA = TA + ra + qa$$

$$MB = TB + rb + qb$$

where ra, rb are the errors in the encoding equipment before quantization and qa and qb are quantization errors (always < 50 feet). (ra + qa) is the (total) error in reported altitude for aircraft A.

Altitudes MA and MB are used as raw altitude data, which are smoothed by the ATARS tracker, and eventually used by the ATARS algorithms. Thus, while the Air Traffic Control (ATC) system has issued clearances for a separation = (ZA - ZB) (such as 500 or 1000 feet), the separation presented to ATARS is (MA - MB).

$$(MA - MB) = (ZA - ZB) + (ra + qa - ea) - (rb + qb - eb).$$

The following error values taken from Reference 3, which reported the results of in-flight measurements of general aviation altimetry errors, have been used in this study:

$$ea, eb = 60 \text{ feet}$$

$$ra, rb = 100 \text{ feet}.$$

These represent one standard deviation values for a sample of general aviation aircraft. Values of about half these can be expected for air carrier aircraft. (See Reference 3.)

4. Tracking errors: Any tracker will have residual errors in altitude and altitude rate, even when an aircraft is maintaining a constant vertical rate. In addition, the tracker will have certain delays and

consequent errors, in tracking vertical maneuvers. The ATARS vertical tracker is used in all simulations made for this study. It is a simple linear (alpha-beta) tracker with constant parameters. This tracker corrects the tracked altitude and altitude rate at each scan with a correction proportional to the difference between the current reported altitude and the altitude predicted for the current scan on the basis of the previous scan's altitude and altitude rate.

E-2.3 Protection Afforded by Current ATARS When Vertical Clearance is Violated

Results indicating the ability of ATARS to provide adequate protection against vertical conflicts are presented in this section. The following variations were made on the basic geometry of Figure E-2-1 to create an appropriate sample of conflicts:

1. Descent Rates: Seven values were used, (all values are in feet per minute): 500, 1000, 1500, 2000, 2500, 3000, 4000.

2. Scanning Delay: Four random samples were drawn from a uniform distribution to reflect scanning delay within the 4.7 second scan.

3. Altimetry Errors: Only the error in the reported altitude is relevant for the clearance broken scenario. Thirteen repetitions of the encounter were made for every combination of descent rate and scanning delay. Different errors in reported altitude, picked from a normal distribution with zero mean and standard deviation of 100 feet (before quantization), were used for each repetition.

Only vertical advisories were issued. The escape acceleration in response to advisories was assumed to be 1/4g (i.e., eight feet per second per second). Pilot response time was assumed to be an

average of four seconds with a spread of three seconds. (I.e., the response time is between 2.5 and 5.5 seconds.)

Figure E-2-4 shows the scatter plot that results from the clearance broken scenario. The scatter plot shows one point for each repetition of the scenario. The point indicates the horizontal and vertical components of separation when the aircraft were at their smallest separation. The point represents the true separation at closest approach. The smallest separation that would be observed by ATARS might be greater or less than this depending on the errors in reported altitude. In the plots shown, horizontal jitter is added purely as an aid to show separation of individual points. Letter codes that correspond to specific vertical rates are as described in the legend.

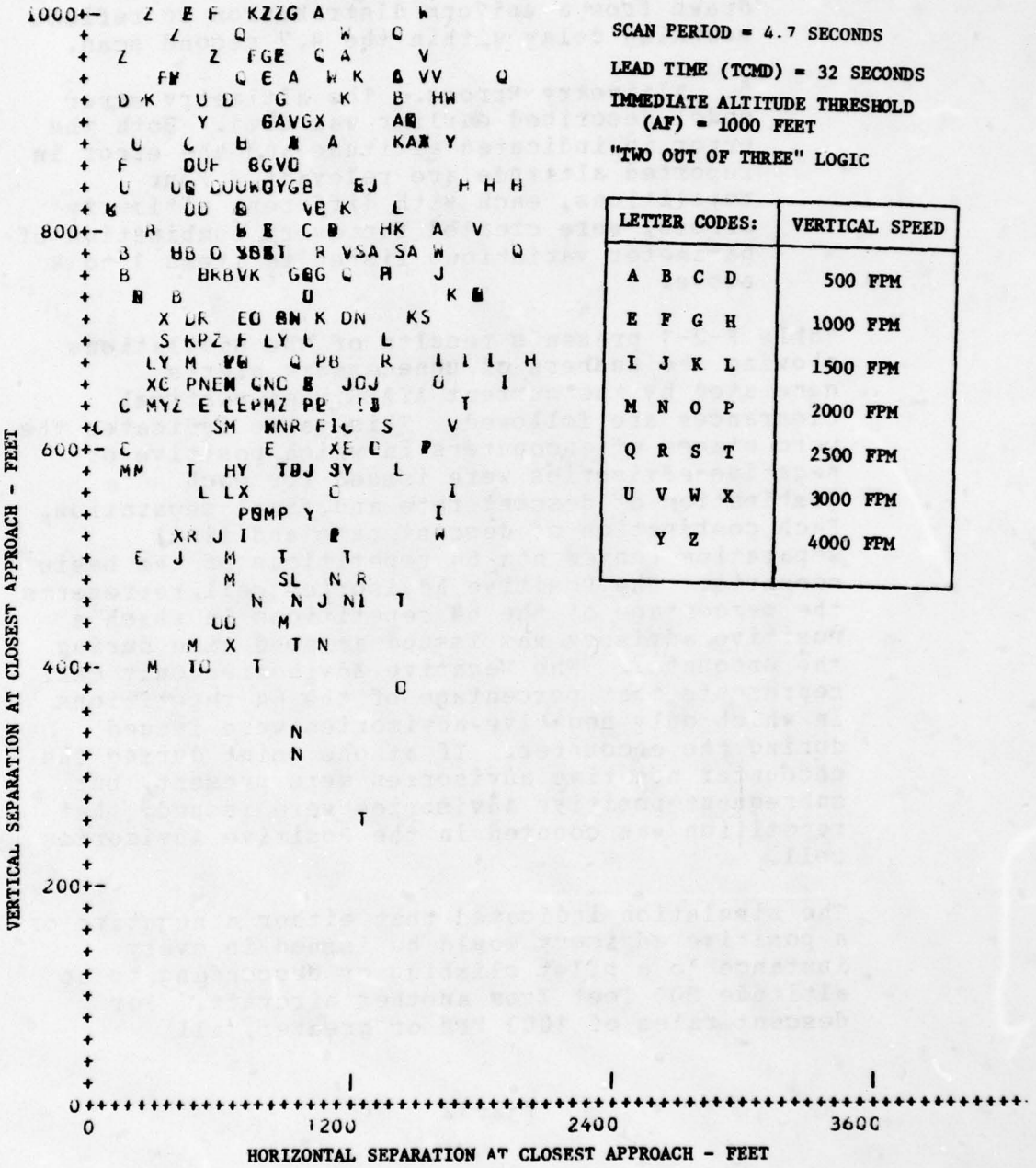
If a scatter plot were made when no ATARS resolution is provided, all the points would lie on the horizontal axis, since all cases simulated represent collision situations. Figure E-2-4 shows the result of ATARS intervention. It shows that the resolution is effective for all descent rates. A initial separation of at least 200 feet is always guaranteed. In fact, the separation achieved by following ATARS commands is usually 400 feet or more.

E-2.4 Unnecessary Alert Performance of Current ATARS

Having demonstrated that the current ATARS provides sufficient protection against conflicts in the vertical dimension, the study next examined how often unnecessary alerts were generated when aircraft followed their clearances.

The basic scenario of Figure E-2-2 was used for this purpose. The following variations were applied:

1. Final Separation after Level-Off. Two values were considered: 500 feet and 1000 feet.



SCAN PERIOD = 4.7 SECONDS

LEAD TIME (TCMD) = 32 SECONDS

IMMEDIATE ALTITUDE THRESHOLD (AF) = 1000 FEET

"TWO OUT OF THREE" LOGIC

LETTER CODES:	VERTICAL SPEED
A B C D	500 FPM
E F G H	1000 FPM
I J K L	1500 FPM
M N O P	2000 FPM
Q R S T	2500 FPM
U V W X	3000 FPM
Y Z	4000 FPM

FIGURE E-2-4
PROTECTION PROVIDED IN VERTICAL CONFLICTS BY CURRENT ATARS

2. Descent Rates (all values in FPM). Seven descent rates were used: 500, 1000, 1500, 2000, 2500, 3000, 4000.

3. Level-Off Acceleration. Four values were used: 1/8g, 1/4g, 3/8g and 1/2g.

4. Scanning Delay. Four random samples were drawn from a uniform distribution to reflect scanning delay within the 4.7 second scan.

5. Altimetry Errors. The altimetry error model described earlier was used. Both the error in indicated altitude and the error in reported altitude are relevant. Four repetitions, each with different altimetry errors, were created for every combination of parameter variations listed in items 1 to 4 above.

Table F-2-1 presents results of the simulations showing the numbers of unnecessary alerts generated by the current ATARS when vertical clearances are followed. This table indicates the percentages of encounters in which positive or negative advisories were issued for each combination of descent rate and final separation. Each combination of descent rate and final separation represents 64 repetitions of the basic scenario. The Positive Advisories cell represents the percentage of the 64 repetitions in which a positive advisory was issued at some time during the encounter. The Negative Advisories Only cell represents that percentage of the 64 repetitions in which only negative advisories were issued during the encounter. If at one point during the encounter negative advisories were present, but subsequent positive advisories were issued, that repetition was counted in the Positive Advisories cell.

The simulation indicated that either a negative or a positive advisory would be issued in every instance to a pilot climbing or descending to an altitude 500 feet from another aircraft. For descent rates of 1000 FPM or greater, all

TABLE E-2-1

PERCENTAGE OF CASES IN WHICH AN ALARM IS ISSUED BY THE CURRENT ATARS WHEN CLEARANCE IS FOLLOWED

FINAL SEPARATION IN FEET	TYPE OF ALARMS	DESCENT RATES IN FEET PER MINUTE						
		500	1000	1500	2000	2500	3000	4000
500	POSITIVE ADVISORIES	0	100	100	100	100	100	100
	NEGATIVE ADVISORIES ONLY	100	0	0	0	0	0	0
1000	POSITIVE ADVISORIES	0	30	59	91	97	100	100
	NEGATIVE ADVISORIES ONLY	27	31	19	0	0	0	0

SCAN PERIOD = 4.7 SECONDS

LEAD TIME (TCMD) = 32 SECONDS

IMMEDIATE VERTICAL THRESHOLD (AF) = 1000 FEET

"TWO OUT OF THREE" LOGIC

POSITIVE ADVISORY THRESHOLD (ASEPL) = 470 FEET

VERTICAL MISS DISTANCE CALCULATION WITH 30 SECOND PROJECTION USED

advisories are positive. Where a final separation of 1000 feet is used, some positive advisories are issued at all descent rates equal to or greater than 1000 FPM. At a descent rate of 500 FPM, negative advisories are issued about a quarter of the time.

These rates of advisories are much higher than desired. The positive advisories are particularly troublesome, because they require responses from both aircraft. With negative advisories, the level aircraft is not required to initiate any action. In these geometries, issuing positive advisories implies a level of threat to the pilot that is not, in fact, present. A discussion of the causes for these high rates is presented in the next section.

F-2.5 Explanation for High Rates of Advisories

Such a high frequency of advisories is due to:

1. LOGIC: The use of the particular magnitude of the immediate vertical searation parameter, AF, and the use of the vertical miss distance variable, VMD.

2. GEOMETRY: The inherent sensitivity of this geometry to high descent rates.

These are considered in turn.

Since AF is 1000 feet in the current logic, ATARS always issues at least a negative command whenever the reported vertical separation is less than 1000 feet. Thus, when an aircraft intends to level off 500 feet above or below another aircraft, a negative advisory is issued when the aircraft comes within 1000 feet (reported) of the other aircraft. It receives a level-off command about 500 feet before its cleared altitude. This effect is also present, although to a lesser degree, for final separations of 1000 feet. When aircraft are flying at 1000 feet final separation, altimetry errors alone can cause reported separations of less than 1000 feet with a probability of somewhat

less than 50%. Thus, due to the effect of the AF parameter, negative advisories will be issued to many aircraft just before they reach their cleared altitudes and will stay on after the aircraft levels off. The negative advisories issued in many of these circumstances have not prevented pilots from reaching their cleared altitudes and the interference in these cases may be considered minimal. However, in the case of low descent rates and a final separation of 500 feet, negative advisories would cause aircraft to level off several hundred feet before reaching their cleared altitude and this could be considered a small nuisance.

Positive advisories represent a greater problem than negative advisories, if they are issued when the pilot actually intends to level off at his cleared altitude. Negative advisories can provide a natural reinforcement to the pilot as he levels off. However, positive advisories imply an immediate threat and an abnormal situation. Yet, with this scenario, they are issued in normal and routine situations.

The cause of the large number of positive advisories is the 30 second projection in the VMD calculation. To illustrate, consider an aircraft descending at 1000 FPM to an altitude 500 feet above another aircraft. When the descending aircraft is within 1000 feet of the other aircraft the conditions for an advisory are met. Suppose the aircraft is 900 feet from the other aircraft when the conditions are met for the second time to satisfy the two-out-of-three logic. The vertical miss distance, which is the vertical separation that the aircraft will have 30 seconds in the future, is computed. It has a value of 400 feet. The value of the vertical miss distance is compared to the ASEPL parameter which has a value of 470 feet. Since the vertical miss distance is less, positive advisories are required. Clearly, all higher descent rates will also result in positive advisories when the intended final separation is 500 feet.

Some positive advisories are also issued when the descent rate is 1000 FPM and the final separation is 1000 feet. These advisories result from a combination of altimetry errors and from the overshoot in tracked altitude introduced by the vertical tracker when a level-off occurs. If there were no altimetry errors and tracking were perfect, there would be no positive advisories in this case.

The current ATARS logic is responsible for many of the unnecessary advisories at lower vertical rates. However, at higher vertical rates it becomes impossible with any logic to provide protection when an aircraft fails to level off, because the level-off is started when there is less than 30 seconds to collision.

Consider the idealized approach geometry in Figure E-2-5. This is similar to Figure E-2-2, except that the level-off is assumed to be instantaneous. Aircraft 2 is flying straight and level. Aircraft 1 is descending at a vertical rate ZD and levels off instantaneously at T = 0. The vertical separation between the two aircraft after Aircraft 1 levels off is FS. There exists horizontal coincidence at all times.

Let TV denote the vertical tau value for the two aircraft. TV = -(vertical separation/vertical closing rate). Let TVMIN denote the minimum vertical tau reached during the entire encounter. Then TVMIN = FS/ZD and will be reached just prior to the instantaneous level off at T = 0.

Table E-2-2 shows the TVMIN values reached for the two final separations for different descent rates. At a final separation of 500 feet, any descent rate greater than or equal to 1000 FPM always yields TVMIN values of 30 seconds or less. Similarly for a final separation of 1000 feet, descent rates of 2000 FPM or more always yield tau values of 30 seconds or less. Experience has shown that 30 seconds is about the smallest warning time that can be used by ATARS. In general, higher vertical rates necessarily cause

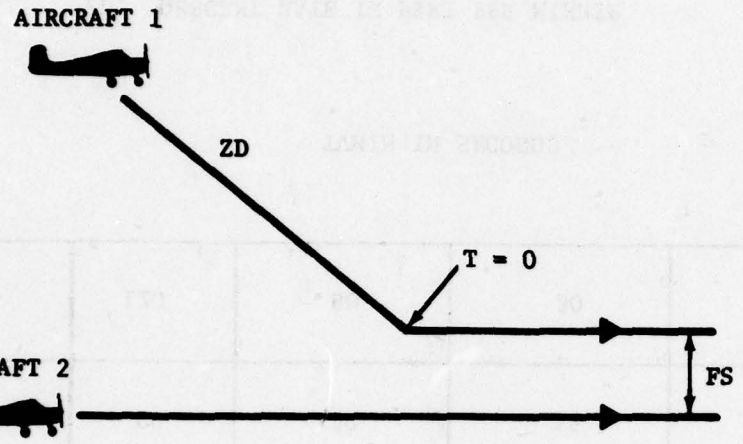


FIGURE E-2-5
IDEALIZED LEVEL-OFF SCENARIO

TABLE E-2-2

TVMIN FOR IDEALIZED LEVEL-OFF SCENARIO

FS \ ZD	500	1000	2000	3000	4000
500	60	30	15	10	7.5
1000	120	60	30	20	15

TVMIN IN SECONDS

ZD: DESCENT RATE IN FEET PER MINUTE

FS: FINAL SEPARATION IN FEET

TVMIN: MINIMUM VERTICAL TAU REACHED DURING AN ENCOUNTER

low tau values to be reached during the encounter.

E-2.6 Deriving Optimum Parameter Values

Using vertical tau as an alert criterion means that alerts are given with a constant time to collision, regardless of descent rates. The vertical separation at the beginning of the escape (or level-off) maneuver is a linear function of descent rate. However, the vertical distance traversed during a constant acceleration escape (or level-off) is a quadratic function of vertical rate. Thus, the tau criterion does not produce the same minimum separation for all descent rates. Results are now presented to show what value of the immediate altitude parameter, AF, or what value of the warning time parameter, TCMD, would be required as a function of descent rate, to provide a desired minimum separation.

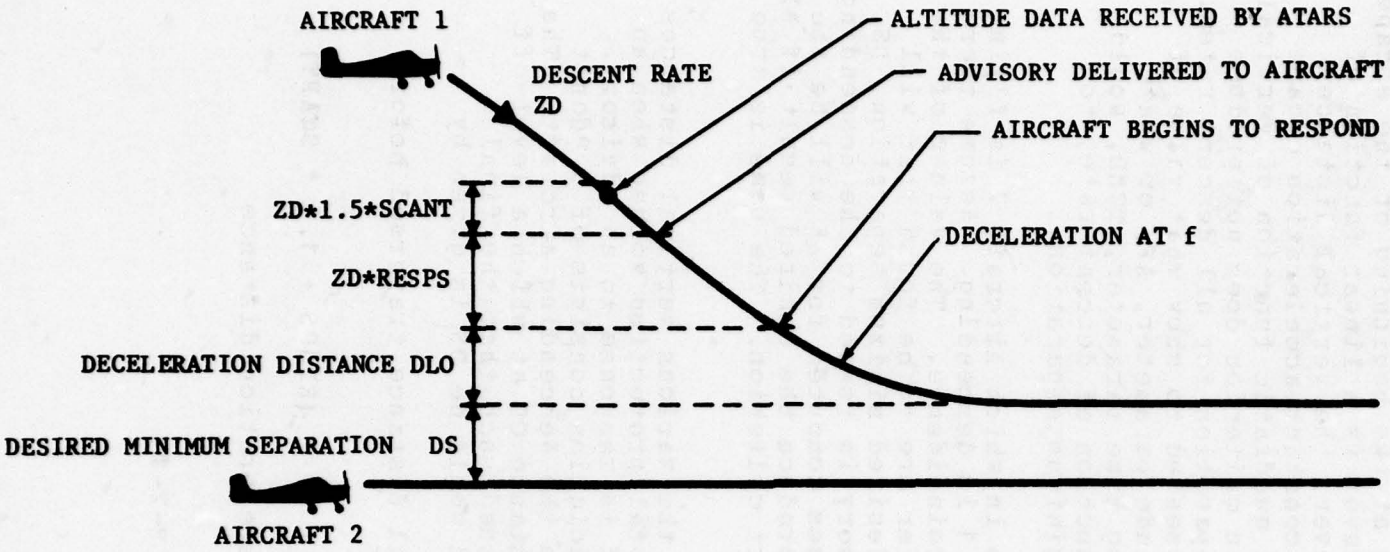
Consider a scenario in which Aircraft 2 is flying level and Aircraft 1 is descending. Assume there exists horizontal coincidence. The values of the AF and TCMD parameter are to be found that will produce a certain desired minimum separation, DS, if a negative advisory is issued to the descending aircraft. The values computed for AF will be the values that would produce the desired result if AF alone were the alert criterion. The same is true for TCMD.

Figure E-2-6 shows the various vertical distances that make up the total protection volume when an aircraft levels off in response to an advisory. Assume that the resolution consists of a "don't descend" command to the descending aircraft. The actual vertical distance CD at which a level-off command must be issued such that the final separation achieved would be DS is given by

$$CD = DS + \text{Total distance traversed before level-off}$$

$$= DS + DLO + ZD * (RESPS + 1.5 * SCANT)$$

where DLO = the deceleration distance



SCANT = SCAN TIME (4.7 SECONDS)

RESPS = PILOT RESPONSE TIME (4 SECONDS)

FIGURE E-2-6
IDEALIZED SCENARIO OF CONFLICT RESOLUTION

ZD = vertical rate of Aircraft 1

RFSPS = Pilot and aircraft response time

SCANT = radar scan time. (The communication delay is between SCANT and 2*SCANT. We use the average, 1.5*SCANT.)

Figure E-2-6 does not show the effects of altimetry errors. The error in reported altitude is 100 feet (one sigma before quantization) for a single aircraft. Quantization error alone has a one sigma value of 29 feet. Therefore the error in reported altitude after quantization will be 110 feet (one sigma). The error in reported separation is the root mean square value of this error for two aircraft and is therefore 154 feet (one sigma). To obtain 98% reliability we would need to protect against errors as large as two standard deviations in magnitude or about 310 feet. The collision avoidance system then needs an immediate altitude threshold AF of (CD + 310) feet or a TCMD value of AF/ZD. These calculations have been made assuming that the alert criteria need be satisfied only once to issue an advisory. If the two-out-of-three requirement is added, then AF should be increased by ZD * SCANT.

Table E-2-3 shows the protection parameters AF and TCMD necessary for different descent rates. The following variable values have been used:

DS = 100 feet

f = 1/4 * g = 8 feet/sec/sec

RESPS = 4 seconds

SCANT = 4.7 seconds

Commands issued if alert criterion met just once.

Table E-2-3 permits an estimation of the protection parameters necessary for any descent rate. Thus, if the descent rate were 1500 FPM, values of AF = 724 feet or TCMD = 29 seconds could

TABLE E-2-3

PROTECTION PARAMETERS AS A FUNCTION
OF DESCENT RATES

DESCENT RATE (FPM)	TOTAL DISTANCE TO LEVEL OFF (LOD) (FEET)	AF = (LOD + 100 + 310) (FEET)	TCMD = AF/ZD (SECONDS)
500	95	505	61
1000	199	609	37
1500	314	724	29
2000	435	845	25
2500	567	977	23
3000	706	1116	22
4000	1012	1422	21

THIS TABLE APPLIES FOR A "SINGLE HIT" LOGIC

(ADVISORIES ARE ISSUED WHEN THE ALERT CRITERIA ARE MET ON JUST ONE SCAN)

be used. Whenever the reported separation was smaller than 724 feet an advisory would be issued. If the pilot responds to this command (with a maximum delay of 4 seconds) the final separation achieved would be at least 100 feet.

The use of a variable threshold is not being advocated here. Rather, this data can be used to find a single value for AF and a single value for TCMD that will serve for all normal descent rates.

In the current ATARS logic, the same detection time threshold (TCMD) is used in both the horizontal and the vertical time tests for an alert. The current logic does not take into account the vertical time to closest approach and the horizontal time to closest approach in deciding whether to resolve a conflict using horizontal or vertical maneuvers. Consequently, it is important that the same alert times continue to be used for horizontal and vertical time tests. Otherwise, insufficient time may be available for resolution in the dimension that has been selected. To illustrate this point, suppose that ATARS were to use 32 seconds for a horizontal time threshold and 20 seconds for a vertical time threshold. If two aircraft converging in altitude were on a collision course, the vertical time to collision would be identical to the horizontal time to collision at any time prior to collision. The alert will only go off when 20 seconds of escape time are left because the vertical criterion will not be satisfied prior to this point. If the ATARS logic has decided that resolution should take place in the horizontal dimension, this 20 seconds of escape time may be insufficient.

The current ATARS logic uses a value of TCMD of 32 seconds with a two-out-of-three requirement. This is equivalent to a value of about 27 seconds without the two-out-of-three requirement. Extensive experience has been gained with ATARS to show that this value is appropriate for the horizontal detection parameter. Thus, the vertical logic should be constrained to use a TCMD

value no smaller than this. It is fruitless to use a value larger than this, because the horizontal time tests, in true collision courses, will prevent an alert from being generated prior to 27 seconds from collision. Hence, a value of TCMD of 27 seconds, for use without a two-out-of-three logic is indicated. Table E-2-3 shows that with such a threshold, protection can be provided for all descent rates that are 2000 FPM or higher. This tau threshold alone, however, will not be enough to provide protection for the slowly descending aircraft. Some of them would have come too close to the level aircraft by the time the tau threshold were recorded. A value of AF of 750 feet is needed to provide protection for slowly descending aircraft. When the two-out-of-three requirement is added, it is found that AF should have a value of 850 feet. However, equivalent protection can be achieved if AF is kept at 750 feet but the TAF parameter used to bypass the two-out-of-three requirement is also set to 750 feet.

To this point, the analysis has assumed that all resolution was being achieved through stopping the vertical rate of the descending aircraft. The logic to determine when positive resolution advisories should be given is now addressed.

The vertical miss distance logic was previously shown to be responsible for numerous unnecessary positive resolution advisories. The preceding analysis has shown that, when one aircraft is descending, safe resolution can be achieved merely by stopping the vertical rate of the descending aircraft. Thus, positive advisories are unnecessary and the vertical miss distance test is not needed in this case. Positive advisories are needed when both aircraft are in level flight at nearly the same altitude. But in this case, the vertical rate is zero and vertical miss distance reduces to just the current vertical separation. Hence, the use of the vertical miss distance calculation in unnecessary. Determining whether positive or negative resolution advisories should be given can be done on the basis of current vertical separation. This can be achieved by

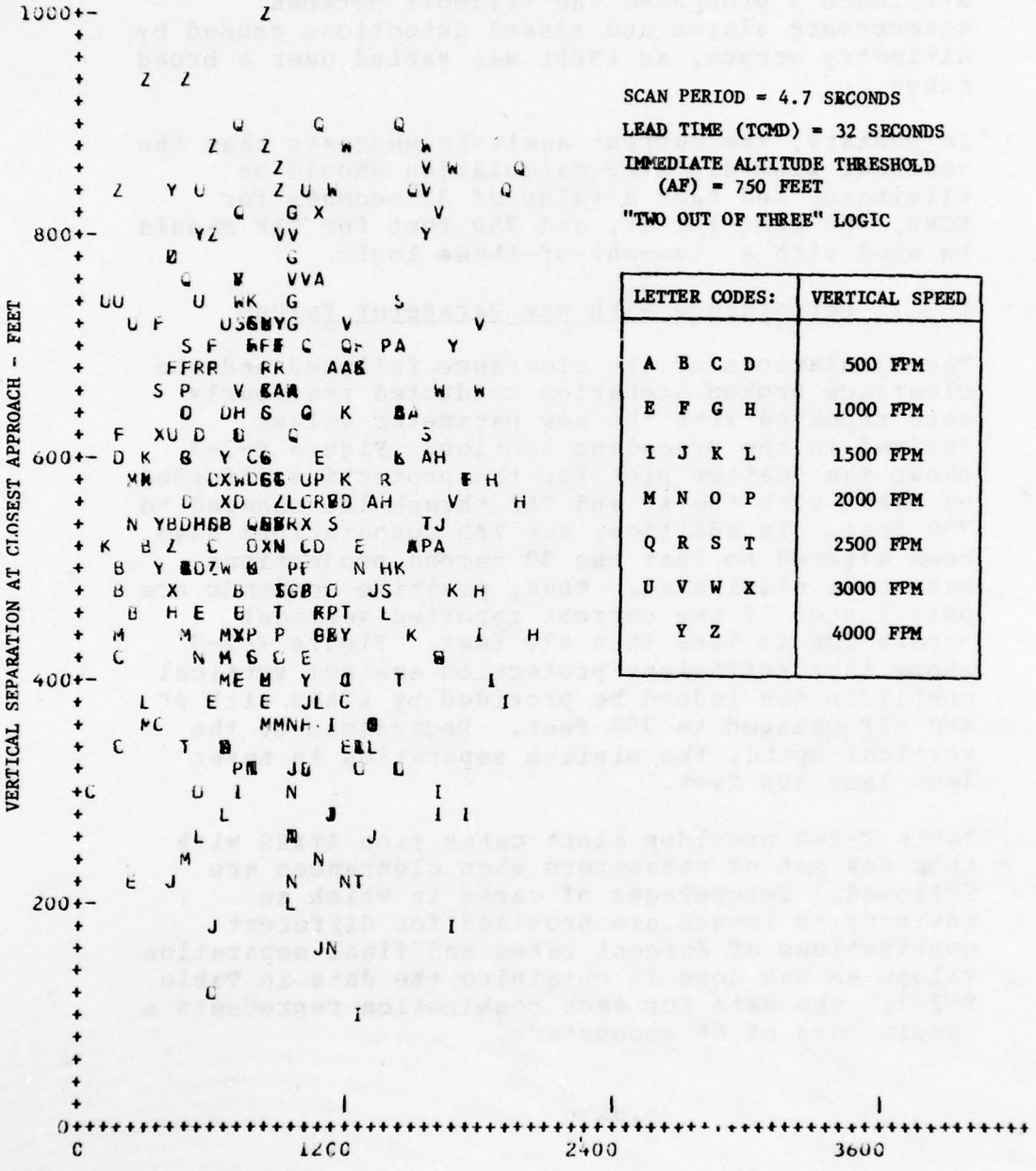
changing the projection time parameter in the vertical miss distance calculation, TVPCMD, from 30 seconds to zero. Then, the current vertical separation will be compared to the threshold, ASEPL, which has a nominal value of 470 feet. This value for ASEPL is recommended by the analysis in Reference 3 when altimetry errors are those found in general aviation aircraft. Reference 3 presented the tradeoff between unnecessary alarms and missed detections caused by altimetry errors, as ASEPL was varied over a broad range.

In summary, the current analysis suggests that the vertical miss distance calculation should be eliminated and that a value of 32 seconds for TCMD, 750 feet for AF, and 750 feet for TAF should be used with a two-out-of-three logic.

E-2.7 Performance With New Parameter Values

The simulations of the clearance followed and the clearance broken scenarios conducted previously were repeated with the new parameter values derived in the preceding section. Figure E-2-7 shows the scatter plot for the protection afforded by ATARS with the AF and TAF thresholds changed to 750 feet. In addition, the VMD computations have been altered so that the 30 second projections have been eliminated. Thus, positive commands are only issued if the current reported vertical separation is less than 470 feet. Figure E-2-7 shows that sufficient protection against vertical conflicts can indeed be provided by ATARS with AF and TAF changed to 750 feet. Regardless of the vertical speed, the minimum separation is never less than 100 feet.

Table E-2-4 provides alert rates from ATARS with this new set of parameters when clearances are followed. Percentages of cases in which an advisory is issued are provided for different combinations of descent rates and final separation values as was done in obtaining the data in Table F-2-1. The data for each combination represents a sample size of 64 encounters.



SCAN PERIOD = 4.7 SECONDS

LEAD TIME (TCMD) = 32 SECONDS

IMMEDIATE ALTITUDE THRESHOLD (AF) = 750 FEET

"TWO OUT OF THREE" LOGIC

LETTER CODES:	VERTICAL SPEED
A B C D	500 FPM
E F G H	1000 FPM
I J K L	1500 FPM
M N O P	2000 FPM
Q R S T	2500 FPM
U V W X	3000 FPM
Y Z	4000 FPM

FIGURE E-2-7
PROTECTION PROVIDED IN VERTICAL CONFLICTS WITH REDUCED ATARS PARAMETERS

TABLE E-2-4

PERCENTAGE OF CASES IN WHICH AN ALARM IS ISSUED WITH REDUCED ATARS PARAMETERS WHEN CLEARANCE IS FOLLOWED

FINAL SEPARATION IN FEET	TYPE OF ALARM	DESCENT RATES IN FEET PER MINUTE						
		500	1000	1500	2000	2500	3000	4000
500	POSITIVE ADVISORIES	0	25	61	77	73	38	25
	NEGATIVE ADVISORIES ONLY	91	75	39	23	27	62	75
1000	POSITIVE ADVISORIES	0	0	0	0	0	0	3
	NEGATIVE ADVISORIES ONLY	0	6	13	59	91	100	97

SCAN PERIOD = 4.7 SECONDS

LEAD TIME (TCMD) = 32 SECONDS

IMMEDIATE VERTICAL THRESHOLD (AF) = 750 FEET

"TWO OUT OF THREE" LOGIC

POSITIVE ADVISORY THRESHOLD (ASEPL) = 470 FEET

NO VERTICAL MISS DISTANCE CALCULATION

Table E-2-4 shows considerable improvement, in terms of lower rates of unnecessary alarms, over the data in Table E-2-1, which provided alert rates for the current ATARS. Both the positive and negative advisory rates are significantly lower. An aircraft descending at 1000 FPM to a cleared altitude which is 1000 feet away from another aircraft will never receive a positive advisory, and will receive a negative advisory 6% of the time. Such an advisory will only be issued to aircraft which are already at their cleared altitude or are very close to it. If a pilot approaches the same altitude at 2000 FPM, he may expect to receive a negative advisory with about 50% probability. Such an advisory would be issued just prior to initiation of the level-off and should not be a problem.

When approaching a final separation of 500 feet at 500 FPM there are no positive advisories. This is primarily because the aircraft has already received a negative advisory when 750 feet away from the level aircraft. At higher descent rates, positive advisories are issued because of greater distances covered by the aircraft after receiving the negative advisories. With a 2000 FPM descent rate, 77% of the encounters result in positive advisories.

The positive advisories issued when approaching a final separation of 500 feet are tied to the threshold of separation, ASEPL, which has a value of 470 feet. The only way the positive advisory counts can be further reduced is by reduction of this threshold. The value of this threshold is dependent upon altimetry errors. Reference 3 shows that reduction of this threshold to a value between 300 and 400 feet causes a three-fold increase in missed detections relative to a threshold of 470 feet. A reduction in ASEPL is not recommended when the aircraft have altimetry errors comparable to those reported in Reference 3.

E-2.8 Dealing With High Vertical Rates

The results of the preceding section show that unnecessary positive advisories can usually be avoided for final separations of 500 feet or 1000 feet if descent rates are kept below 1000 FPM. The Airman's Information Manual (AIM) (Reference 4) recommends a practice that would satisfy this condition. The AIM states: "Descend or climb at an optimum rate consistent with the operating characteristics of the aircraft to 1000 feet above or below the assigned altitude, and then attempt to descend or climb at a rate of 500 feet per minute until the assigned altitude is reached."

Suppose a level aircraft is 1000 feet away from the cleared altitude of a descending aircraft. If the pilot of the descending aircraft were to follow the recommendations of AIM, he would reduce his vertical rate to 500 FPM when within 2000 feet of the level aircraft. With AF and TAF = 750 feet and ASEPL = 470 feet, such an aircraft will trigger neither positive nor negative advisories. If the level aircraft were 500 feet away from the cleared altitude of the descending aircraft, the latter would have slowed to a 500 FPM rate at 1500 feet vertical separation from the other aircraft. Shortly before reaching its cleared altitude, it would usually receive a negative advisory.

While 500 FPM is a reasonable rate for small aircraft, it may be too low in practice for high performance aircraft. Aircraft have been observed in real world traffic samples using higher rates to approach the level-off. The use of a vertical speed limit procedure has been suggested as a means of limiting the vertical speed of aircraft in such situations. If such a procedure were implemented, ATARS would calculate the maximum vertical speed permitted and would uplink this limit for display in the cockpit of the aircraft with the vertical rate. Such a limit would only be displayed when a threat aircraft was present at an adjacent cruising altitude and the aircraft with the vertical rate was actually exceeding the vertical rate limit.

In order for the vertical speed limit to be effective in avoiding some positive advisories, it must be issued at a time well in advance of the positive advisory alert time. The horizontal alert time for the vertical speed limit advisory should be the same as the vertical alert time. With longer alert times for vertical speed limit advisories, ATARS may issue vertical speed limits in situations in which a pilot in visual flight conditions would prefer to maneuver horizontally. Since ATARS has no knowledge of the cleared altitudes for aircraft, it does not know when a pilot might prefer to maintain his vertical rate and make a horizontal avoidance maneuver.

The flashing Proximity Warning Indicator (PWI) message, which is provided by the current ATARS, could also be expected to alert the pilot to the presence of another aircraft above or below his cleared altitude. It would be natural to expect that a pilot would reduce his vertical rate as he approaches his cleared altitude, when he has received a flashing PWI message indicating another aircraft above or below his altitude. If the pilot were descending and encountered a threat when not near a cleared altitude, the flashing PWI would provide an indication of the threat but would not unnecessarily constrain the pilot's actions. A vertical speed limit advisory at an early alert time would constrain the pilot's vertical rate, even though other actions might avoid a conflict. With the presence of the flashing PWI message in the ATARS design, the use of an additional procedure for limiting vertical speeds well in advance of positive advisories is considered unnecessary.

A second type of vertical speed limit logic has been suggested. In this logic, the vertical speed limit advisory would be issued at the same alert time as would a positive or negative resolution advisory. The vertical speed limit advisory would be issued in place of a positive or negative advisory in certain situations involving aircraft with high vertical rates. This type of logic shows promise of reducing the positive advisory

rate in these types of encounters in which horizontal closest approach occurs before the aircraft reach the same altitude. The application of this type of vertical speed limit to ATARS should be investigated in an additional study.

E-2.9 Considerations When One Aircraft is Unequipped

The preceding investigation was conducted under the assumption that both aircraft were equipped with ATARS and would be able to receive resolution advisories. However, the logic that was developed is also appropriate for the case in which one aircraft is not equipped with ATARS. It is the purpose of this section to explain why this is so.

In the current ATARS, the TCMD alert time parameter is increased for an encounter in which one aircraft is unequipped, if the unequipped aircraft has a horizontal speed more than 1.5 times greater than the speed of the equipped aircraft. Otherwise, the value for TCMD is the same as for encounters with both aircraft equipped. Assume that the equipped aircraft is descending and the unequipped aircraft is level. The previous study showed that safe separation could be provided simply by stopping the vertical rate of the descending aircraft. Hence, in this case the same parameters as used for encounters with both aircraft equipped would be adequate. The same parameters will be used unless the unequipped aircraft is more than 1.5 times faster than the equipped aircraft. If this latter condition exists, it implies that the equipped aircraft is a lower performance aircraft which would be likely to use lower vertical rates. When lower rates are used, the alerts are triggered by the current altitude separation threshold, AF, which has the same value whether or not both aircraft are equipped. Only if the unequipped aircraft were more than 1.5 times faster than the equipped aircraft, and the equipped aircraft were descending at a higher rate, would a difference be noted. The difference is that negative advisories would be issued at a slightly higher altitude. No

difference in the presentation of positive advisories would be noted.

Now consider the case in which the unequipped aircraft is descending and the equipped aircraft is level. In this case, it is not possible to stop the vertical rate of the descending aircraft. However, the current ATARS design, in the advisory selection logic, senses for an encounter in which an unequipped aircraft has a vertical rate towards the equipped aircraft. When this situation is found, resolution is performed with horizontal maneuvers.

Thus, the changes recommended previously for the case of both aircraft equipped also seem justified when one aircraft is unequipped.

E-3. EFFECT OF TEN SECOND SCAN PERIOD

It has been suggested that ATARS might provide a limited form of service in some en route airspaces by being implemented as a part of long-range DABS sensors which have a scan period of 10 seconds. Reference 2 has shown that ATARS cannot provide a satisfactory service as an aid to see-and-avoid using this scan period. However, the preceding analysis has been extended to present results with a 10 second scan period that could be used in considering ATARS for a more limited role.

The communications delay due to the scanning radar is between 1 and 2 times the scan period. (This is true for a single hit logic. An additional scan period of delay is introduced if a two-out-of-three requirement is added.) To show this, consider that the altitude separation, for a scenario with one aircraft descending, drops below the immediate altitude threshold just an instant after the radar has scanned the aircraft. ATARS will not trigger the alert until the following scan and will not deliver the advisory to the aircraft until the scan after that. In this case, the communications delay is two scan periods. If the altitude separation drops below the threshold just an instant before the radar scans the aircraft, the delay is one scan period. On the average the delay is 1.5 times the scan period.

If the DABS scan period were ten seconds, the communications delay would be an average of 15 seconds, or 9 seconds more than that for the 4-second scan period. This increase in communications time requires an increase in the detection threshold values (the tau-threshold and the immediate altitude threshold). This increase in the communications time would also require changes to the horizontal conflict detection parameters.

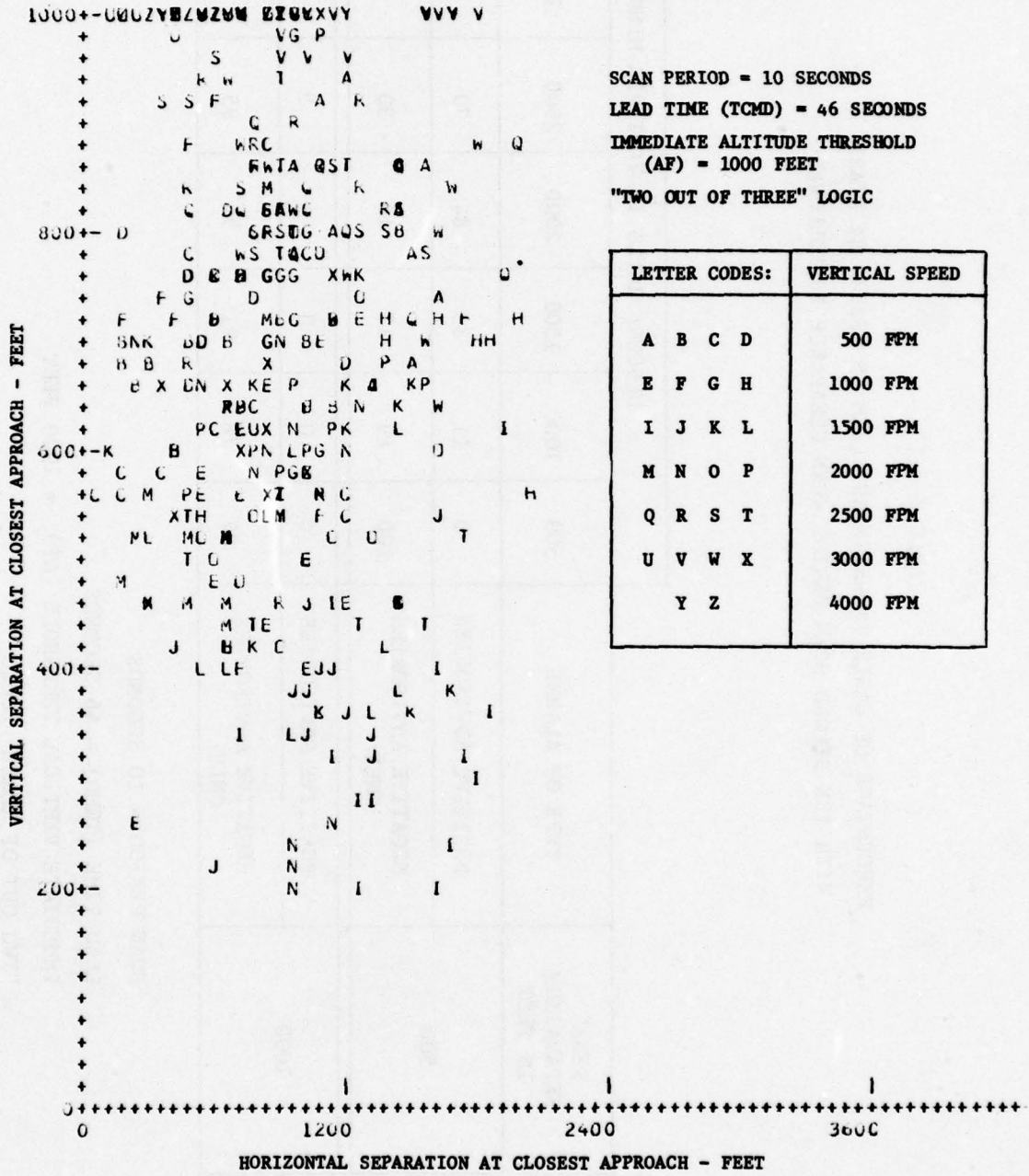
The maximum usable value for AF is 1000 feet since this value represents the minimum IFR-IFR vertical separation and since IFR aircraft are routinely separated by this distance. An analysis similar

to that conducted in Section E-2.6 was used to find an initial value for TCMD, given that AF was constrained to be 1000 feet. Several simulations of the clearance broken scenarios of Figure E-2-1 were conducted, in which the values of TCMD were varied around this initial value. The smallest value of TCMD, that provided no minimum separations less than 100 feet on the scatter plot, was selected as the appropriate value to be used with a 10 second scan period. This value was 46 seconds. Figure E-3-1 shows the scatter plot for TCMD = 46 seconds and AF and TMF = 1000 feet.

Table E-3-1 shows the unnecessary alarms produced with the above parameter set when the descending aircraft follows its level-off clearance. The same scenario as in Figure E-2-2 was used. Variations in parameters were made to create a sample size of 64 encounters for each combination of final separation and descent rate, as was done previously.

The data in Table E-3-1 can be compared to that in Table E-2-4. The unnecessary alarm performance of ATARS with a ten second scan period is seen to be worse than with a 4.7 second scan period, particularly at a final separation of 1000 feet. At 500 FPM descent rates, with the ten second scan period, negative advisories are issued about a third of the time. At higher rates, negative advisories are issued most of the time. The impact of the larger communications delay is to create more variability in the resolution. In order to provide assurance that vertical separations of at least 100 feet can be achieved, more conservative resolution must be accepted in some cases. This is evident in comparing Figures E-2-7 and E-3-1. With the ten second scan period, many more encounters result in final separations in excess of 1000 feet.

From these results, it may be concluded that ATARS could provide protection against broken altitude clearances with a ten second scan period, if a look-ahead time of 46 seconds were used in conjunction with an immediate altitude threshold



SCAN PERIOD = 10 SECONDS

LEAD TIME (TCMD) = 46 SECONDS

IMMEDIATE ALTITUDE THRESHOLD (AF) = 1000 FEET

"TWO OUT OF THREE" LOGIC

LETTER CODES:	VERTICAL SPEED
A B C D	500 FPM
E F G H	1000 FPM
I J K L	1500 FPM
M N O P	2000 FPM
Q R S T	2500 FPM
U V W X	3000 FPM
Y Z	4000 FPM

FIGURE E-3-1
PROTECTION PROVIDED IN VERTICAL CONFLICTS BY ATARS WITH TEN SECOND SCAN PERIOD

TABLE E-3-1

PERCENTAGE OF CASES IN WHICH AN ALARM IS ISSUED BY ATARS
WITH TEN SECOND SCAN PERIOD WHEN CLEARANCE IS FOLLOWED

FINAL SEPARATION IN FEET	TYPE OF ALARMS	DESCENT RATES IN FEET PER MINUTE						
		500	1000	1500	2000	2500	3000	4000
500	POSITIVE ADVISORIES	0	11	83	84	70	59	53
	NEGATIVE ADVISORIES ONLY	100	89	17	16	30	41	47
1000	POSITIVE ADVISORIES	0	0	0	6	5	11	12
	NEGATIVE ADVISORIES ONLY	27	78	91	94	95	89	88

SCAN PERIOD = 10 SECONDS

LEAD TIME (TCMD) = 46 SECONDS

IMMEDIATE VERTICAL THRESHOLD (AF) = 1000 FEET

"TWO OUT OF THREE" LOGIC

POSITIVE ADVISORY THRESHOLD (ASEPL) = 470 FEET

NO VERTICAL MISS DISTANCE CALCULATION

of 1000 feet. However, the number of unnecessary alarms and the number of excessive separations would be increased substantially over those experienced with a 4.7 second scan period.

The acceptability of service provided by ATARS with a ten second scan period depends upon how well pilots can adapt to these unnecessary alarm rates and upon their attitudes toward an ATARS service that provides less opportunity to acquire another aircraft before receiving resolution advisories. The current ATARS provides flashing PWI messages at 45 second tau values. Reference 2 has shown that it is difficult for pilots to acquire another aircraft at tau values in excess of 45 seconds. Since the resolution advisory must be given at 46 seconds, a flashing PWI presented in advance of this time would probably not be effective.

E-4. SUMMARY AND CONCLUSIONS

The current version of ATARS (i.e., as described in Reference 1) provides sufficient protection against vertical conflicts involving aircraft with altimetry errors comparable to those of a wide segment of the general aviation population. Assuming a 4 second delay in pilot and aircraft response to advisories, and a 0.25g vertical acceleration, vertical conflicts can be effectively resolved by issuing vertical advisories alone.

However, when an aircraft levels off at an ATC-assigned altitude 500 or 1000 feet away from another aircraft, with which it is in horizontal conflict, the current ATARS issues a large number of unnecessary alarms. With two minor changes in the ATARS logic and parameter values, these unnecessary alarms can be significantly reduced without loss of protection. These changes are:

1. Reduction of the immediate altitude threshold (AF) from 1000 feet to 750 feet. A corresponding reduction in the two-out-of-three bypass parameter (TAF) to 750 feet should also be made.

2. Elimination of the the vertical miss distance calculation (achieved by setting TVPCMD to zero).

If an aircraft that is descending at a rate less than 2500 FPM levels off at 1000 feet above another aircraft, ATARS, with the changes described above, will either issue no advisories or will issue negative advisories when the aircraft is very close to level-off. For a final separation of 500 feet, the aircraft will receive negative advisories as it approaches the cleared altitude if it has a vertical rate less than 1000 FPM. At vertical rates of 1000 FPM or more, a significant number of unnecessary advisories will be experienced, either in the form of negative advisories issued well before the aircraft reaches the assigned altitude or in the form of

unnecessary positive advisories.

Even with these modifications, the ATARS logic is sensitive to abrupt level-offs from high descent rates. To alleviate this sensitivity, a form of selective vertical speed control would be desirable. One approach would be for ATARS to advise the pilot of an aircraft with a vertical rate to limit his rate if there is a threat aircraft near his assigned altitude. To be most effective in avoiding unnecessary positive or negative advisories, such a vertical speed limit advisory should be given 15-20 seconds earlier than the positive or negative alert time. However, ATARS does not have knowledge about assigned altitudes and ATARS cannot know when a pilot would prefer to maintain his vertical rate and avoid his traffic with a horizontal maneuver. Thus, it is recommended that the flashing PWI message from the current ATARS logic be used to indicate when a pilot should reduce his vertical rate. Pilots should be made aware that if they receive a flashing PWI indicating a threat below, when they are descending at a high rate, there is a high probability of unnecessary alarms. The use of a vertical speed limit advisory issued at the same alert time as used for positive and negative advisories should be studied further for possible application in the ATARS logic.

The protection parameters required for vertical conflict resolution increase with an increase in the radar scan period. With a ten second scan period, ATARS would need 46 seconds of lead time in conjunction with an immediate altitude threshold of 1000 feet to guarantee a minimum vertical separation of 100 feet. The increase in the number of unnecessary alarms and the increase in number of resolutions with excessive separation, above those for a 4.7 second scan period are significant. Whether these increases are acceptable depends upon the application envisioned for ATARS with a ten second scan period. This judgment cannot be made here.

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3. Mundra, A. D., "Implications of Altimetry System Errors for Collision Avoidance Systems", The MITRE Corporation, McLean, Virginia, MTR-7232, May, 1977.

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APPENDIX F

IMPACT OF IMPROVED VERTICAL SURVEILLANCE ON AUTOMATIC SEPARATION ASSURANCE

A. D. Mundra

F-1. INTRODUCTION

The Air Traffic Control Radar Beacon System (ATCRBS) is capable of automatically obtaining altitude data from aircraft equipped with altitude reporting transponders. Such a transponder, in response to Mode-C interrogations by the radar, downlinks the aircraft's barometric altitude quantized in hundreds of feet. The altitude is thus downlinked once per scan of the ground radar. This constitutes the vertical surveillance available in the current Air Traffic Control (ATC) system.

The Federal Aviation Administration (FAA) has deployed an automatic separation assurance system element called En Route Conflict Alert (see Reference 1) in the en route portion of the National Airspace System (NAS). En Route Conflict Alert serves as an aid to the ATC controllers to help reduce involuntary violations of aircraft separation minima for aircraft in flight. The FAA is also actively developing two other fully automated separation assurance system elements: Automated Traffic Advisory and Resolution Service (ATARS) and Beacon Collision Avoidance System (BCAS). Since vertical surveillance is the primary means of monitoring separation in the vertical plane, it is of key importance in all these separation assurance system elements.

Appendix F showed that it is difficult to provide protection against broken (violated) altitude clearances when the scan period of the radar is 10 seconds. En Route Conflict Alert operates with data from radars that have scan periods of 10 or 12 seconds. Certain improvements in vertical surveillance that would be possible with the Discrete Address Beacon System (DABS) seem to offer potential for better protection against broken altitude clearances. This study identifies the possible improvements in the current vertical surveillance system. The benefits that might be realized from these improvements are analyzed in detail in Section F-2. This study was conducted using the En Route Conflict Alert logic as the

vehicle for showing the impact of improvements in vertical surveillance. The impact of these improvements on ATARS was then inferred from the results of the study with Conflict Alert. Section F-3 contains a summary of the results and conclusions.

F-2. VERTICAL SURVEILLANCE IMPROVEMENTS

Section F-2.1 describes the problem of altitude clearance violations and the logic incorporated in the current En Route Conflict Alert system to deal with it. Sections F-2.2, F-2.3, F-2.4, and F-2.5 identify various possible improvements and their impact on the performance of En Route Conflict Alert. Section F-2.6 presents the impact that these improvements would have on ATARS.

F-2.1 Altitude Clearance Violations and En Route Conflict Alert

The National Aeronautics and Space Administration (NASA) has been conducting an Aviation Safety Reporting Program since 1977. Data from this effort has identified violations of altitude clearances as a significant source of near mid-air collisions in aviation. Further, most of the altitude deviations reported in this data base involved Instrument Flight Rules (IFR) aircraft (i.e., aircraft within the ATC System). (See Volume II.) Protection against altitude clearance violations is thus a tangible service that En Route Conflict Alert might provide. En Route Conflict Alert specifically uses altitude clearance information in its threat detection logic and also contains criteria for detecting violations of altitude clearances. This logic is now reviewed.

Conflict Alert projects each of its aircraft 120 seconds into the future and checks for violation of certain separation standards. If two aircraft are projected to be within 1000 feet of each other vertically, and conflict conditions in the horizontal dimension are also satisfied, a conflict is declared. If an aircraft has a vertical rate which results in the aircraft crossing its assigned altitude within the 120 second projection, En Route Conflict Alert assumes that the aircraft will continue its rate to the assigned altitude and then will proceed level at that altitude. Thus, the aircraft will be assumed to be at the assigned altitude at the end of the

120 second projection interval.

Conflict Alert has a tracking logic which derives estimates of vertical velocity by tracking the Mode-C altitude reports from the transponders. However, Conflict Alert has a feature that disables the tracking logic when an aircraft is within 200 feet of its assigned altitude. In this case, the aircraft is considered to be level and at its assigned altitude.

Conflict Alert has an additional feature which checks for broken altitude clearances. If at some point both the tracked altitude and the reported altitude are found to be more than 200 feet past the assigned altitude, then Conflict Alert assumes that the clearance has been broken and projection with the current tracked vertical rate is resumed. If there should be another aircraft in such a position that the pair would satisfy conflict conditions (i.e., violation of separation standards within 120 seconds), then a conflict would be declared.

Mode-C altitude reports are rounded to the nearest hundred feet. Tracked altitude can be on either side of reported altitude depending upon the track's history. Considering constant rate climbs or descents, the liklihood of the tracked altitude being greater than the reported altitude is the same as it being less. If the difference between tracked and reported altitude were not more than 100 feet, then the logic for declaring a broken altitude clearance would be equivalent to a simple logic which only monitors reported altitudes and declares the clearance broken when the report is 300 feet past the assigned altitude. In this study, this simplified logic is used to avoid the problem of estimating tracked altitudes. The extent to which this logic will declare "clearances broken" more often than the actual Conflict Alert algorithm depends upon the expected value of the difference between tracked altitude and reported altitude. This difference is assumed to be small.

Figure F-2-1 shows the implications of this simplified "clearance broken" logic. Aircraft 1 is assigned altitude ZA1 and is descending at DR feet per minute. If Aircraft 1 follows its clearance, it will level-off at ZA1 which means that the altitude indicated by its altimeter will then be ZA1. The reported altitude will be ZR1, which is different from ZA1 by CE1, the aircraft's correspondence error.

If Aircraft 1 should break its clearance, its altitude will continue to decrease past ZR1. At point B where its reported altitude becomes (ZA1 - 300), Conflict Alert declares that it has broken its clearance and resumes projection with the vertical rate DR. Suppose there is another aircraft, Aircraft 2, in close horizontal proximity. Let CE2 be its correspondence error. Let ZSEP be the nominal separation (ZA1 - ZA2) between the two aircraft. The computed time to coaltitude, TCO, will then be given by:

$$TCO = (ZA1-300-ZR2)/DR$$

$$= (ZA1-ZA2-300-CE2)/DR$$

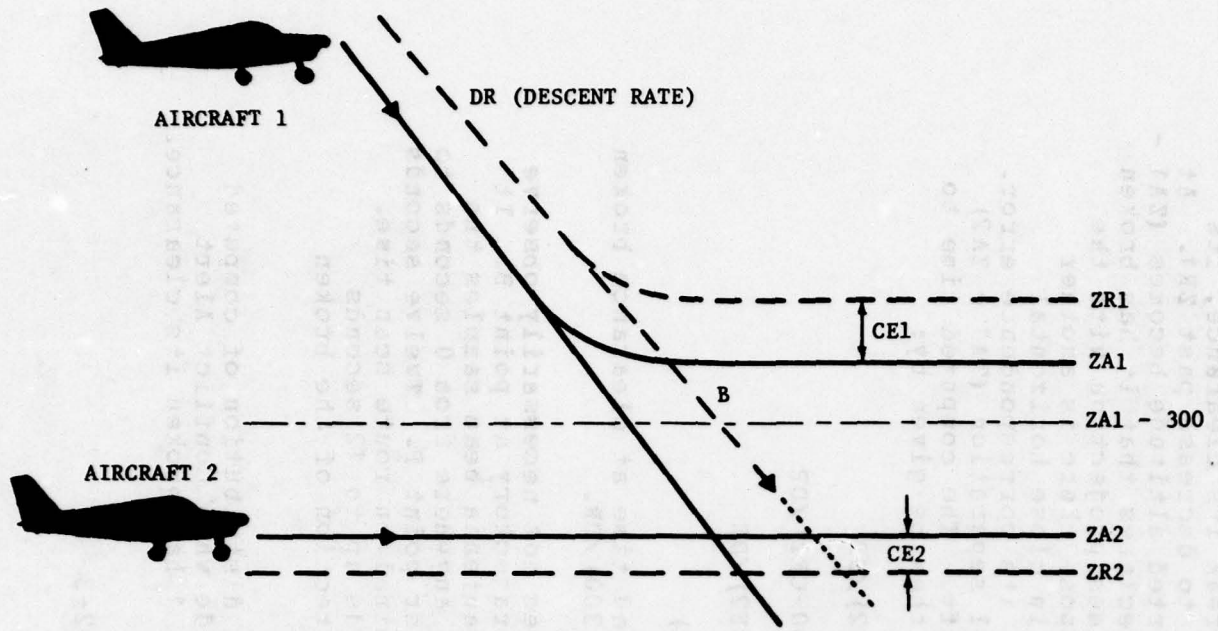
$$= (ZSEP-300-CE2)/DR$$

$$= TNL-(CE2/DR)$$

Where TNL = nominal lead time at clearance broken declaration = (ZSEP - 300)/DR.

The radar, however, does not necessarily observe the broken-clearance trajectory at point B. It has to wait until the antenna beam samples the aircraft, which may be anywhere from 0 seconds to one full scan time after point B. Twelve seconds is assumed for the nominal en route scan time. Thus, the scan time adds up to 12 seconds additional delay in detection of the broken clearance.

Figure F-2-2 shows the distribution of computed lead times to coaltitude when Conflict Alert declares that Aircraft 1 has broken its clearance.



ZA1 = ASSIGNED ALTITUDE FOR AIRCRAFT 1

ZR1 = REPORTED ALTITUDE FOR AIRCRAFT 1

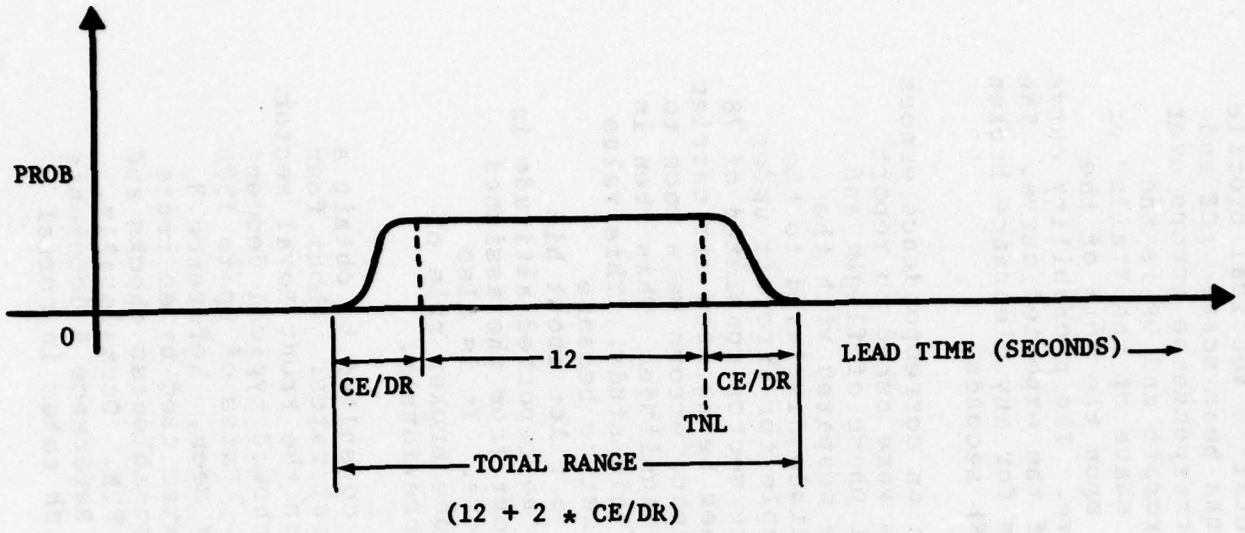
CE1 = CORRESPONDENCE ERROR FOR AIRCRAFT 1 = ZR1 - ZA1

ZA2 = ASSIGNED ALTITUDE (HENCE = INDICATED ALTITUDE) FOR AIRCRAFT 2

ZR2 = REPORTED ALTITUDE FOR AIRCRAFT 2

CE2 = CORRESPONDENCE ERROR FOR AIRCRAFT 2 = ZR2 - ZA2

FIGURE F-2-1
CLEARANCE FOLLOWED/BROKEN SCENARIO



CE = LIMITS OF CORRESPONDENCE ERROR

DR = DESCENT RATE IN FEET PER SECOND

TNL = NOMINAL LEAD TIME TO COALTITUDE

FIGURE F-2-2
LEAD TIME TO COALTITUDE (IN REPORTED ALTITUDE) WHEN CONFLICT ALERT DECLARES CLEARANCE BROKEN

This distribution represents the lead times that will be seen when aircraft with varying correspondence errors follow the clearance-broken scenario of Figure F-2-1. Also included are variations resulting from differing phase relationships of the aircraft's vertical profile with respect to the antenna beam scan. +CE and -CE are the limits of correspondence errors over the population of all aircraft and DR is the descent rate. The exact shape of the "tails" of the distribution depends upon the form of the correspondence error curve. The probability curve shown is thus a sketch of the expected curve. The total range of lead times for any clearance broken scenario is (12 + 2*CE/DR) seconds.

Reference 2 presents data on correspondence errors gathered in 1973. Pilots were asked to report their altitude in a level phase of flight and their verbal reports were compared with the transponder reported altitude displayed to the controller. The data sample for aircraft under 20,000 feet in an en route sector consisted of 78 reports, about half of them being from air carrier aircraft. All correspondence errors were seen to be less than 200 feet in magnitude. This then is the value used for CE in this study. This value is consistent with ATC practice because controllers will question a pilot about his altitude if they observe the reported altitude in level flight to be different from the assigned altitude by 300 feet or more. It is also consistent with the altitude broken rule of Conflict Alert described previously.

Various data sources were consulted to obtain a reasonable range for descent rates. About four hours of data gathered from the Front Royal sector of the Washington Center showed typical descent rates of 1000 to 3000 FPM. Rates of up to 3500 FPM were also occasionally seen. Reference 3 gives climb and descent rates used by en route facilities for Mode-C reasonableness checks and shows rates of up to 4500 FPM. Occasionally, higher rates are listed. Reference 4 documents manufacturer's data on climb rates in normal

conditions. There, climb rates of up to 3000 FPM are found for different aircraft types. For the current study a range of vertical rates from 1000 FPM to 4000 FPM is analyzed.

With values for CE and DR known, it is possible to estimate the lead times to coaltitude when Conflict Alert discovers that an aircraft, cleared to some altitude above another aircraft, has broken its clearance. Thus, for 1000 feet assigned separation and a vertical rate of 1000 FPM for the descending aircraft, the nominal lead time to coaltitude would be (1000 - 300)/(1000/60) = 42 seconds. Due to the correspondence error of the level aircraft and scan time delays, the lead time in any particular situation may be anywhere between 54 seconds and 18 seconds. (See Figure F-2-2.)

Table F-2-1 tabulates the lead times to coaltitude for various combinations of separations and descent rates. Assigned separations of up to 4000 feet and descent rates of up to 4000 FPM are considered. It should be noted that this lead time has to provide for controller reaction time, pilot/aircraft reaction time and the actual escape time. Thus, the actual escape time available in case of danger is smaller than these lead times by the sum of controller reaction time and pilot and aircraft reaction times.

Table F-2-1 reveals the Conflict Alert capability to protect against altitude clearance violations at a glance. The upper right hand region (cells marked H) contains large lead times. This means that when nominal separation is large and descent rates are small, Conflict Alert can provide ample warning againt an impending conflict that may result from a broken clearance. (Horizontal conflict conditions are assumed to be satisfied.) In the lower left region of the table (cells marked L) very low vertical lead times are seen. Thus, if an aircraft with a high vertical rate breaks a clearance when there is a small assigned separation, the amount of warning provided by Conflict Alert is small. Sometimes, as in the

TABLE F-2-1

RANGES OF LEAD TIMES TO COALTITUDE WHEN CONFLICT ALERT DETECTS BROKEN CLEARANCES

ASSIGNED SEPARATION IN FEET

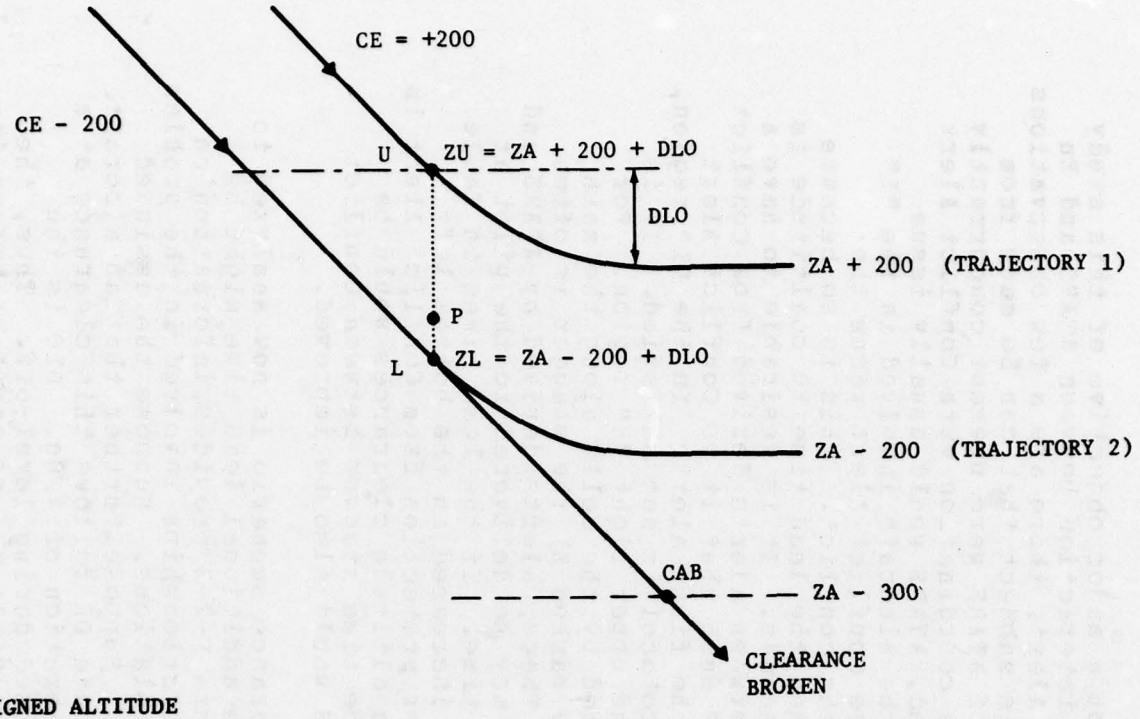
DESCENT RATE IN FPM

	1000	2000	3000	4000
1000	54 ↔ 18 M	114 ↔ 78 H	174 ↔ 138 H	NO ALERT
2000	27 ↔ 3 L	57 ↔ 33 M	87 ↔ 63 H	117 ↔ 93 H
3000	18 ↔ -2 L	38 ↔ 18 L	58 ↔ 38 M	78 ↔ 58 H
4000	14 ↔ -5 L	29 ↔ 10 L	44 ↔ 25 L	59 ↔ 40 M

cases of the negative lead times, the warning may be issued after the reported altitudes have crossed each other.

While it was not a major objective of this study to analyze the interaction between ATARS and En Route Conflict Alert, there are a few observations relative to this subject that can be made from Table F-2-1. If ATARS were present concurrently and appropriate coordination with Conflict Alert were not assured, ATARS would usually issue advisories to the aircraft involved in the "L" conflicts before Conflict Alert warns the controller of the conflict. This is so because ATARS alerts when the lead time to coaltitude is less than 32 seconds. It is desirable to have a time stagger between alerts derived from Conflict Alert and ATARS such that it is Conflict Alert that provides the first alert. In the "L" region, this desired protocol is not satisfied. It is satisfied in the upper right "H" region. For cases represented by the cells along the main diagonal (those marked M) the stagger is often insufficient. There, alerts derived by ATARS and Conflict Alert may be delivered to the pilot at about the same time. If the lead times in Table F-2-1 could be increased in the bottom left regions, greater protection from Conflict Alert in cases of broken altitude clearances would be obtained and the time stagger between Conflict Alert and ATARS would also be improved.

The broken clearance scenario is now analyzed to determine where additional lead time might be provided. Figure F-2-3 provides information on the altitude relationships involved in the problem of clearance violations. Suppose the assigned altitude is ZA. Suppose further that an aircraft descending at rate DR follows this clearance at a level-off acceleration of 1/8g. DLO is the distance traversed during level-off. Thus, the aircraft starts its level-off DLO feet before its assigned altitude. Because of correspondence error, the trajectory is CE feet from the indicated altitude trajectory. Since CE is no more than 200 feet, the reported altitude



ZA = ASSIGNED ALTITUDE

DLO = DISTANCE TRAVERSED DURING LEVEL-OFF

ASSUME 1/8g FOR LEVEL-OFFS

ALL LEVEL-OFFS START BETWEEN POINTS L AND U

ALL TRAJECTORIES ARE IN REPORTED ALTITUDES

FIGURE F-2-3
ALTITUDE RELATIONSHIPS OF THE "CLEARANCE BROKEN" DECISION POINT

trajectory of level-off is always contained within the two trajectories shown in Figure F-2-3, bounded by CE = +200 and -200. Thus, all aircraft that intend to level-off with a constant 1/8g acceleration start their level-offs between (and including) points U and L. The exact starting point is dependent upon the correspondence error of each aircraft. If an aircraft does not start its level-off prior to some point P (before L), the alert logic must still allow for the possibility that its correspondence error may be such that it may start its level-off later. Thus, no system can make a decision about an aircraft breaking its clearance until after point L.

If an aircraft doesn't show indications of leveling-off, at a point below ZL as determined by any particular scheme, then the alert logic may declare that it has broken its clearance. Conflict Alert waits for the aircraft to reach 300 feet below ZA (point CAB) to make this decision. This waiting distance from point L to point CAB and the time taken to traverse it is a function of the descent rate. Table F-2-2 tabulates this waiting time for different descent rates. It is seen to be about eight seconds, regardless of the descent rate.

The delay due to scan time is above and beyond this waiting time. As already discussed, the scan time delay can be up to 12 seconds. Any scheme that tries to improve upon Conflict Alert in its function of issuing a warning when a clearance is broken aims at shrinking these two delays. The improvements that might have an impact in reducing the delays are now considered.

It has already been shown that correspondence errors of up to 200 feet in magnitude can be found on aircraft at en route altitudes. Therefore, an aircraft following its clearance can report an altitude of up to 200 feet past the cleared altitude even when following its clearance. Thus, a sufficient condition for declaring a violation is to find the aircraft at an altitude more than 200 feet past the cleared altitude. This is the

TABLE F-2-2

INHERENT DELAY IN DETECTION OF BROKEN CLEARANCE IN CONFLICT ALERT

DESCENT RATE IN FPM	(ZL - ZA) IN FEET	TIME OF TRAVERSE BETWEEN L AND CAB WHEN CLEARANCE IS BROKEN (SECONDS)
1000	-166	8
2000	-61	7
3000	113	8
4000	356	10

NOTE: See Figure F-2-3 for explanation of symbols.

current Conflict Alert logic. Such a scheme effectively waits for a full level-off to take place before making any decisions. However, one could monitor the trajectory and/or the aircraft vertical speed to see if the aircraft is in the process of leveling off. Three ways of doing this are considered:

a. Monitor reported altitudes to obtain indications of reduced vertical rates.

b. Reduce the quantization level of reported altitudes and monitor reported altitudes to obtain an indication of reduced vertical rates.

c. Downlink aircraft vertical speed obtained from aircraft's own instruments to yield indications of reduced vertical rate.

For each method, the analysis establishes how quickly a reliable indication of a level-off can be made and estimates to what extent the current eight seconds waiting time can be reduced. The effect of reducing the additional delay due to scan time by increasing the data rate is also evaluated.

F-2.2 Data Rate Improvements

It was shown in Section F-2.1 that the radar scan time, SCANT, adds an inherent random delay in the detection of an event and that this delay is uniformly distributed between zero and SCANT seconds. In other words, if an event occurs nominally at T seconds, the actual time of detection by the radar will be anywhere between T and (T + SCANT) seconds.

If the en route radar were upgraded to provide a back-to-back antenna capability, then, for a 12 second data rate radar, the effective scan time would be six seconds. The delay due to scan time would then be uniformly distributed between zero and six seconds. For a four-second scan time radar, the delay would be distributed over zero to

four seconds.

Table F-2-3 shows, for Conflict Alert, the lead times to coaltitude at the time a broken clearance is detected if a four second scan were being used. Table F-2-3 is essentially similar to Table F-2-1, except that the lower bounds in Table F-2-3 are eight seconds higher than those in Table F-2-1. This improvement in Table F-2-3 eliminates those cases in Table F-2-1 where the detection times were negative. The average improvement obtained is four seconds. The average improvement realized by a back-to-back antenna would be three seconds.

F-2.3 Detection of Level-Off by Downlinking Vertical Speed

One obvious way of detecting a reduction in an aircraft's vertical speed is to monitor the vertical speed obtained from the aircraft's own instruments. If a data link capability were available (as it would be in DABS), then the vertical speed obtained from an appropriate airborne instrument could be downlinked to the ground and monitored automatically by the separation assurance system.

A commonly used vertical speed instrument on aircraft is the rate of climb indicator. This instrument has an inherent delay in responding to changes in vertical speed of up to 15 seconds (see Reference 5). In Section F-2.1 it was observed that the total delay that could possibly be eliminated is itself only eight seconds. Therefore, the rate of climb indicator seems inappropriate as a source for downlinking vertical speed information.

Instruments do exist which provide a so-called "instantaneous vertical speed". These instruments are an improvement on the rate of climb instruments in that they make use of accelerometers to augment the conventional detection of static pressure changes by a detection of the inertial acceleration. The transfer function of one such instrument has been

TABLE F-2-3

RANGES OF LEAD TIMES TO COALTITUDE WHEN CONFLICT ALERT DETECTS BROKEN CLEARANCES WITH FOUR SECOND DATA RATE

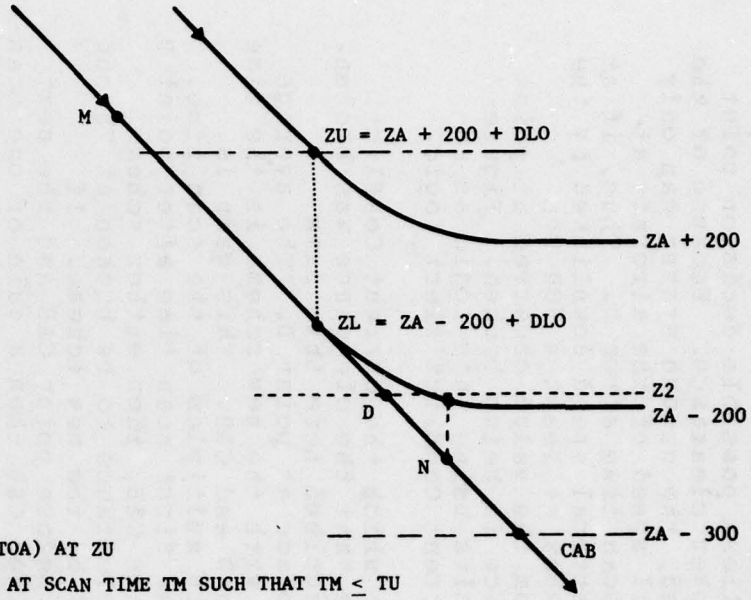
ASSIGNED SEPARATION IN FEET

DESCENT RATE (FPM)	1000	2000	3000	4000
1000	54 ↔ 26	114 ↔ 86 H	174 ↔ 146 H	NO ALERT
2000	27 ↔ 11 L	57 ↔ 41	87 ↔ 71	117 ↔ 101
3000	18 ↔ 6 L	38 ↔ 26 L	58 ↔ 46	78 ↔ 66 H
4000	14 ↔ 3 L	29 ↔ 18 L	44 ↔ 33	59 ↔ 48

analyzed. The transfer function represents the response of vertical speed instruments and transducers which are proprietary products of Teledyne Avionics of Charlottesville, Virginia. This analysis has shown that such an instrument is capable of indicating a 500 FPM change in four seconds when the vertical speed is changing at an acceleration of 1/8g. (The actual speed change in four seconds is 1000 FPM.) If the acceleration were 1/4g, it would show a 500 FPM change in two seconds. It is clear, that the "instantaneous vertical speed" is not really achieved "instantaneously". However, it does provide a faster response than the conventional rate of climb indicators in the early part of the speed change. This is a meaningful improvement for the current purposes since the interest is in obtaining an indication that the aircraft is leveling off.

Suppose a perceived change of 500 FPM in the direction of level-off is sufficient indication of leveling off. An algorithm is now described to declare clearance violations when vertical speed is downlinked using DABS.

Figure F-2-4 shows the geometry of a clearance being followed and a clearance being broken. This figure is esentially similar to Figure F-2-3. A descending aircraft that levels off may follow a trajectory anywhere between the two trajectories marked by correspondence errors of +200 and -200 feet. Thus, depending upon the value of the correspondence error, the aircraft could start leveling off at an altitude as high as ZU. With the rate of descent available on the downlink from scan to scan, and assuming that the descent rate remains constant, it is possible to estimate the time of arrival at ZU. Let TM be the last scan time before the estimated time at ZU and let DR be the best estimate of the descent rate at that scan time. Depending upon the value of correspondence error, the aircraft may start leveling off at an altitude as low as ZL. Even if it starts its level-off at ZL, it won't be until four seconds later at point D that its vertical speed



ZA = ASSIGNED ALTITUDE

TU = ESTIMATED TIME OF ARRIVAL (TOA) AT ZU

DR = BEST VERTICAL RATE ESTIMATE AT SCAN TIME TM SUCH THAT TM $\leq$ TU

TL = ESTIMATED TOA AT ZL

T2 = (TL + 4)

TN = SCAN TIME SUCH THAT TN $\geq$ T2

IVS = VERTICAL SPEED AT TN

ZRN = REPORTED ALTITUDE AT TN

LOGIC:
- IF ((SCAN TIME = TN AND IVS $\leq$ DR - 500) OR (ZRN $\leq$ ZA - 300)) THEN CLEARANCE BROKEN
- CLEARANCE FOLLOWED ASSUMED OTHERWISE

FIGURE F-2-4
DECISION POINTS AND LOGIC FOR DECLARING BROKEN CLEARANCE WITH VERTICAL SPEED DOWNLINKED

instrument will reflect a change of 500 FPM. If at this time the vertical speed does not show a reduction by 500 FPM, it is certain that the aircraft is not intending a level-off (at least not with an acceleration less than that which produces a level-off distance of DLO). Thus, point D is the earliest possible decision point for declaring a broken clearance. Because of the sample time involved, the ground system can only acquire the vertical speed of the aircraft at point N, the next scan time after D. Thus, if at scan time TN the vertical speed downlinked by the aircraft does not show at least a 500 FPM reduction in DR from the value observed at point M, then the clearance is being broken. Figure F-2-4 presents results using this logic as an addition to the current Conflict Alert logic.

CAB is the point at which the current Conflict Alert would declare that the clearance was broken. With the scheme described here this same declaration takes place at point D. The average gain in alert time with the new scheme is the time of traverse between D and CAB. This gain is actually realized in multiples of the scan time. Thus, if TN were the first scan time after point D and TN occurred after CAB, then either scheme would declare the clearance to be broken at TN and no gain is realized by the new scheme. If however, TN occurs before point CAB and the next scan time occurs after CAB then a gain of one scan time would be realized. On the average, since TN can occur anywhere between D and CAB (and beyond) with equal probability, the gain with the current scheme is equal to the time of traverse between D and CAB. The exact value of scan time does not affect this average. It would, however, affect the range of alert time gains. The altitude of point D changes with the descent rate and so does the time of traverse between D and CAB. Table F-2-4 tabulates the time of traverse between D and CAB for different descent rates. Note that about four seconds of gain is realized over the current Conflict Alert.

Table F-2-5 shows the lead times to coaltitude in

TABLE F-2-4

AVERAGE GAIN OVER CONFLICT ALERT AT SAME DATA RATE
WHEN VERTICAL SPEED IS DOWNLINKED

DESCENT RATE (FPM)	AVERAGE GAIN OVER CONFLICT ALERT AT SAME DATA RATE (SECONDS)
1000	4
2000	3
3000	4
4000	6

NOTE: Average Gain = Time of Traverse Between Points D and CAB in Figure F-2-4.

TABLE F-2-5

RANGES OF LEAD TIMES TO COALTITUDE IN DECLARING CLEARANCE BROKEN
WHEN VERTICAL SPEED IS DOWNLINKED AT FOUR SECOND DATA RATE

ASSIGNED SEPARATION IN FEET

DESCENT RATE (FPM)	1000	2000	3000	4000
1000	58 ↔ 30	118 ↔ 90 H	178 ↔ 150 H	NO ALERT
2000	30 ↔ 14 L	60 ↔ 44	90 ↔ 74 H	120 ↔ 104 H
3000	22 ↔ 10 L	42 ↔ 30	62 ↔ 50	82 ↔ 70 H
4000	20 ↔ 9 L	35 ↔ 24 L	50 ↔ 39	65 ↔ 54

Conflict Alert when broken clearances are declared with this improvement. This table should be compared to Table F-2-3 and Table F-2-1. When sufficient alert time already exists, the extra improvement added by this method is of no particular value. However, in the region of low alert times these few extra seconds will imply slightly more protection. In the medium range of alert times, this gain would somewhat improve the staggering in alert times between Conflict Alert and ATARS if they were in operation simultaneously.

F-2.4 Detection of Level-Off Through Monitoring of Reported Altitude

Changes in an aircraft's vertical speed can be deduced from the aircraft's altitude profile. The next two sections present the theoretical basis for and algorithmic implementation of this possibility. Section F-2.4.1 discusses the results when altitude is reported in hundred feet quantization levels and Section F-2.4.2 discusses the results when altitude reporting with little or no quantization may be available.

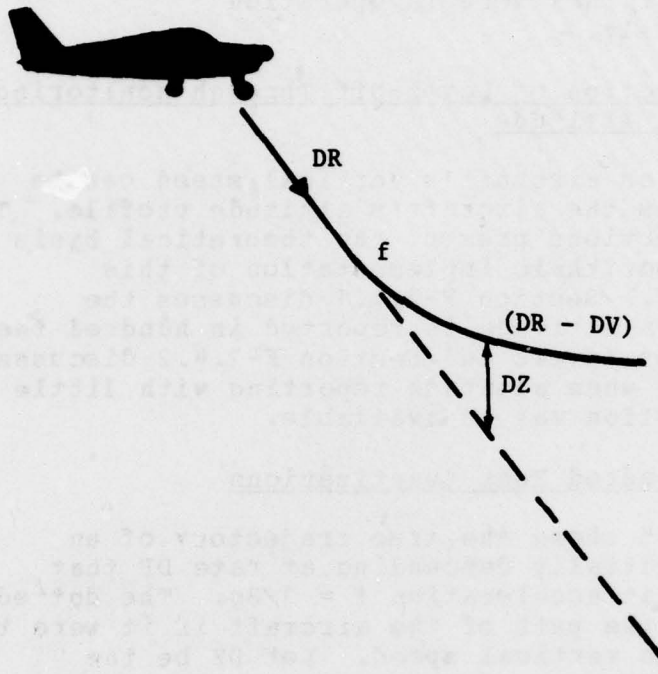
F-2.4.1 Hundred Feet Quantizations

Figure F-2-5 shows the true trajectory of an aircraft initially descending at rate DR that levels off at acceleration f = 1/8g. The dotted line shows the path of the aircraft if it were to maintain its vertical speed. Let DZ be the altitude difference between the constant rate descent path and the leveling off trajectory at any given point during the level-off, and let (DR-DV) be the vertical speed of the aircraft at the same point. DV is thus the amount of reduction in the aircraft's vertical speed since the level-off began.

Then

$$DZ = (DV * DV)/(2 * f).$$

Given f, there is a unique correspondence between



DR = INITIAL DESCENT RATE

f = LEVEL-OFF ACCELERATION

FIGURE F-2-5
CORRESPONDENCE BETWEEN ALTITUDE AND SPEED DIFFERENTIALS

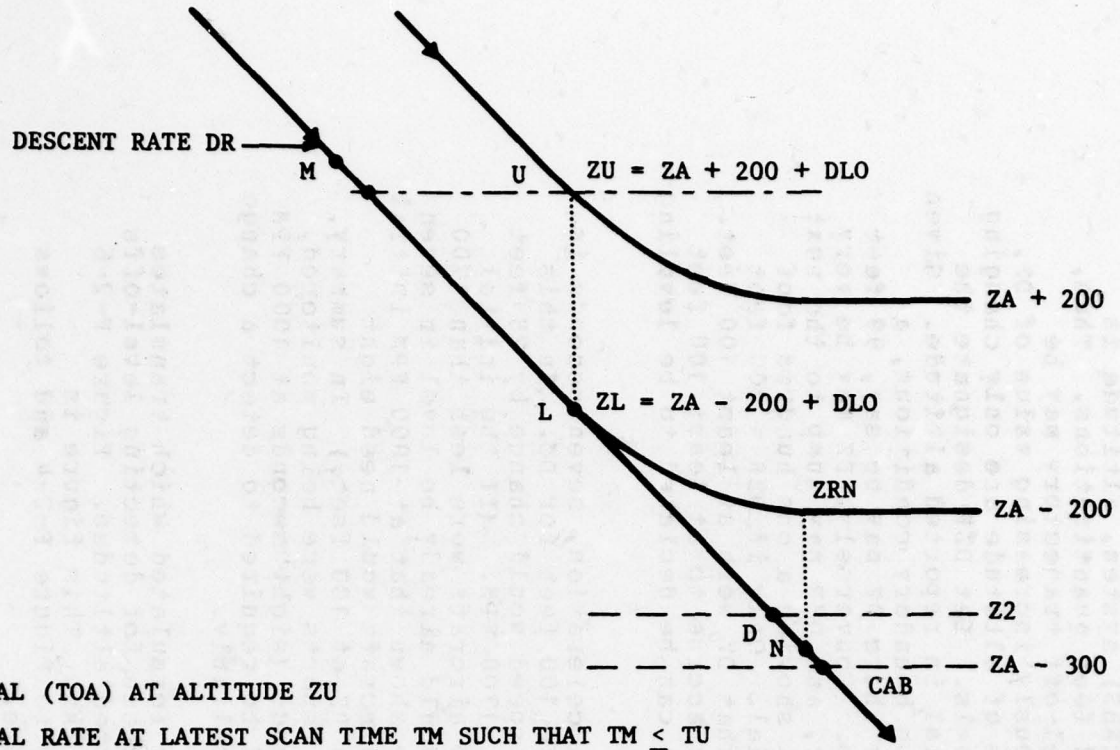
DZ and the amount of deceleration DV. DZ is called the "altitude differential".

In the current (ATCRBS) system, altitude is reported in hundred feet quantizations. Thus, while the true level-off trajectory may be accruing a continuously increasing value of DZ, the reported values of altitude are only changing in hundred feet levels. Let DZR designate the altitude differential in reported altitude. Given certain quantization boundary conditions, a situation may exist where DZ may be say, 99 feet but DZR may be zero. Conversely, DZ may be very small, say one foot, and DZR may jump to the next quantization level, showing a one hundred foot altitude differential. Only if DZR = 200 feet could one be sure that DZ were at least 100 feet. Conversely, DZ must accrue to at least 100 feet before the aircraft can be declared to be leveling off.

At 1/8g level-off acceleration, seven seconds is needed to accumulate 100 feet for DZ. In this time, the vertical speed would change by 28 feet per second or about 1700 FPM. (If the initial descent rate of the aircraft were less than 1700 FPM, the aircraft would already be level in seven seconds. It can be shown that at 1000 FPM initial descent rate, the aircraft would need eight seconds to accure a DZ of 100 feet.) In summary, if ATCRBS altitude reports were being monitored, at least seven seconds (eight seconds at 1000 FPM initial rate) would be required to detect a change in vertical speed reliably.

An algorithm is now formulated which translates this idea into a scheme for detecting level-offs by monitoring reported altitudes. Figure F-2-6 depicts this algorithm. This figure is essentially similar to Figure F-2-4 and follows the same nomenclature.

Let TU be the estimated time at the altitude above which no level-offs would start. Let DR be the best estimate of the vertical rate at the latest scan time TM such that TM is less than or equal to



ZA = ASSIGNED ALTITUDE

TU = ESTIMATED TIME OF ARRIVAL (TOA) AT ALTITUDE ZU

DR = BEST ESTIMATE OF VERTICAL RATE AT LATEST SCAN TIME TM SUCH THAT TM $\leq$ TU

TL = ESTIMATED TOA AT L

TD = 7 SECONDS (EIGHT SECONDS IF DR $\leq$ 1000 FPM)

T2 = TL + TD

TN = SCAN TIME SUCH THAT TN $\geq$ T2

Z2 = ZL - TD * DR

ZN = Z2 - (TN - T2) * DR

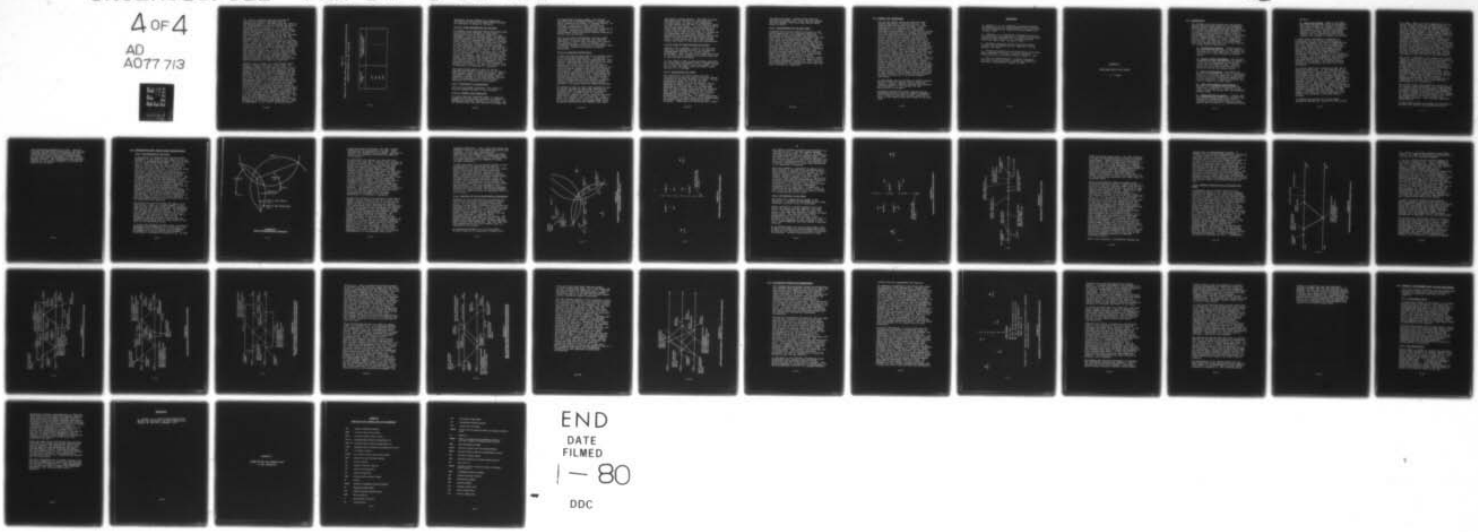
ZRN = REPORTED ALTITUDE AT TN

LOGIC : ● IF ((SCAN TIME = TN AND ZRN < ZN + 200) OR (ZRN $\leq$ ZA - 300)) THEN CLEARANCE BROKEN
OTHERWISE CLEARANCE FOLLOWED IS ASSUMED

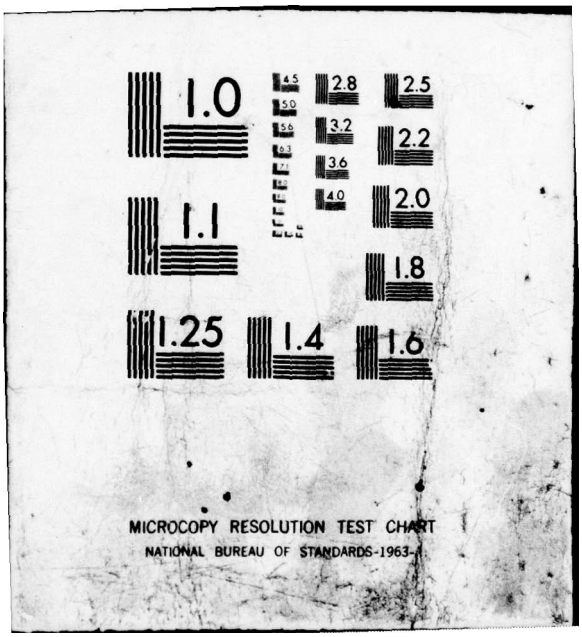
FIGURE F-2-6
DECISION POINTS AND LOGIC FOR DECLARING BROKEN CLEARANCE BY MONITORING REPORTED ALTITUDES

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TU. Such an estimate would be obtained by tracking the reported altitudes with an appropriate tracker. Depending upon the value of its correspondence error, an aircraft may start a level-off as late as point L. Let TL be the estimated time of arrival at L. At least seven more seconds (eight if DR is 1000 FPM) must pass before the reported altitude can be used to indicate whether the aircraft is in fact leveling off. Point D is this decision point and the decision time TD is given by TD = TL + 7. An altitude report can only be obtained at the scan times. Let TN be the earliest scan time such that TN is greater than or equal to TD. Let ZRN be the reported altitude at point N, obtained by linearly projecting the aircraft path at descent rate DR from the altitude at TM. If ZRN < ZN + 200 then the aircraft is declared to be not leveling-off. This check is added to the current Conflict Alert logic (which declares the clearance broken if the reported altitude reaches 300 feet below the cleared altitude) to comprise the algorithm that monitors reported altitudes for level-off.

Conflict Alert without this added scheme would declare a broken clearance at point CAB. By arguments similar to those used in Section F-2.3, the average gain in alert time using this latter scheme is the time of traverse between D and CAB. Although this average gain is independent of the magnitude of the scan time, the actual gain seen in any particular event is in multiples of the scan time. Table F-2-6 provides values for the average gain in alert time realized by monitoring reported altitudes. It is seen that this gain is essentially zero. This means that the present scheme of detecting broken clearances cannot be improved upon by monitoring the reported altitudes that arrive in levels of 100 feet. It should also be pointed out that this scheme is equivalent to detecting changes in the vertical speed using an altitude rate obtained by tracking altitude. (The same altitude differential would be required whether the decision was being made with altitude differences or vertical speed differences.) Thus, no improvement in the time of declaring broken

TABLE F-2-6

AVERAGE GAIN OVER CURRENT CONFLICT ALERT AT SAME DATA RATE WHEN REPORTED ALTITUDE (QUANTIZED IN HUNDREDS OF FEET) IS MONITORED

DESCENT RATE (FPM)	TIME GAINED BY MONITORING REPORTED ALTITUDES
1000	0
2000	0
3000	1
4000	3

clearances can be realized by tracking the vertical rate during level-offs, when altitudes are available in levels of 100 feet.

F-2.4.2 Finer Quantization of Altitude

The effect on the decision points described above if altitude were available at much finer quantization, say in one-foot levels, is now evaluated. With fine quantization, the smallest altitude differential DZ (see Figure F-2-3) that could indicate a leveling-off would be a quantity greater than the expected altitude noise or scan to scan variation. Suppose the scan to scan altitude variation in normal flying conditions is 10 feet one-sigma and that any DZ less than 30 feet may be attributable to noise. DZ of at least 30 feet must be accrued to believe that a level-off is taking place. At 1/8g acceleration, this takes four seconds. Thus, with a no-quantization system, the decision must be delayed until four seconds after point L (see Figure F-2-6) and then the reported altitude must be compared to the projected altitude to see if the difference is greater than 30 feet. If not, the aircraft would be declared to be breaking its clearance.

The time between points L and D in the no-quantization system is observed to be the same as when vertical speed is being downlinked. Thus, the benefit gained in issuing an alert when a clearance is broken is the same whether vertical speed is downlinked or altitude with finer quantization is available to the ground.

F-2.5 Sensitivity to Assumptions

This section briefly discusses the effect of various assumptions made in this analysis.

F-2.5.1 Descent Rate Estimation

In every algorithm discussed above, an implicit assumption has been made regarding the ability to estimate the aircraft descent rate correctly. In the methods which use only reported altitudes (and

not downlinked vertical speed), the initial altitude rate is obtained through a tracker and would inherently be subject to tracker errors. In addition to the scan to scan variations in altitude, quantization level and data rate contribute to errors in descent rate estimation by trackers. Smaller data intervals and lower quantization levels facilitate greater accuracy of descent rate estimation.

Even in the case of downlinked vertical speed, some smoothing of the vertical rate would be necessary. A smaller data interval will improve this estimate also. Errors in descent rate estimation contribute to errors in estimated times of arrival, causing false alarms or missed detections.

F-2.5.2 Level-Off Acceleration

A value of 1/8g has been used as the nominal value of the level-off acceleration. In practice, a range of accelerations would be encountered. Non-constant accelerations during level-offs are quite likely. Even step-wise level-offs may be encountered, which could present some special difficulties in realizing the effectiveness of an algorithm which assumes level-offs with constant acceleration. Assuming a constant acceleration, the minimum expected acceleration determines the value of ZU (see Figure F-2-3). Lower values of acceleration imply earlier times at which the initial descent rate must be recorded. Earlier times in determining DR imply greater errors in estimated times of arrival and hence greater probability of false alarms or missed detections.

The amount of gain in alert time realized by any of the new methods for detecting level-off is dependent upon the maximum value of level-off acceleration. A larger value of level-off acceleration implies a smaller level-off distance (DLO) and a smaller time to level off. Thus, point L in Figures F-2-4 and F-2-6 occurs later. If, on the other hand, the maximum value of the level-off acceleration were smaller than 1/8g,

then point L occurs earlier. The time to accrue the thresholds, (100 feet in the quantized altitude system, 30 feet in the unquantized altitude system and 500 FPM in the vertical speed system) are also longer. It can be shown that if the maximum expected level-off acceleration is 1/16g, then the average gain over the current Conflict Alert logic will be about six seconds for the downlinked vertical speed system, eight seconds for the non-quantized altitude system and about four seconds for the quantized-altitude system. These values are two to four seconds higher than those at 1/8g level-off acceleration.

F-2.5.3 Scan to Scan Altitude Variations

Section F-2.4.2 assumes a value of 10 feet one-sigma for the random variation in the reported (unquantized) altitude in a normal flying environment. This is made up of random variations in the static port pressure and random variations in altitude due to pilotage.

If this value of scan to scan variation were five feet one-sigma, the benefit from a no-quantization system would increase by about one second. If it were 20 feet one sigma, then the benefit would decrease by 1.5 seconds.

F-2.6 Implications for ATARS

The availability of either finer altitude quantization or vertical speed would also improve detection of vertical maneuvers in ATARS. It has already been shown that in the 100 feet quantizaton system, a vertical maneuver can be detected in seven seconds. For either a non-quantization altitude system or a downlinked vertical speed system, four seconds are required. Thus, a gain of three seconds in any situation that requires reliable detection of a vertical maneuver can be achieved. This assumes an acceleration value of 1/8g. If these improvements were available in ATARS, about three seconds would be gained in situations involving vertical maneuvers. ATARS does not currently have a level-

off detection logic. Further study would be required to develop such a logic and to estimate how much benefit these extra few seconds would imply for ATARS.

F-2.7 Implications for the Data Link

Providing the vertical speed of aircraft to the ground implies use of a downlink capability. If the downlink were to be useful for detecting level-offs or broken altitude clearances, the data would have to be downlinked every scan. This would mean that aircraft would routinely have to make 112 bit downlink replies rather than the 56 bit replies currently required by the DABS system. There are not enough bits available to downlink vertical speed in the 56 bit messages. Providing altitude with finer quantization would also require downlink capability, since the altitude would most likely be provided in a separate data block supplementing the routine altitude information which is quantized to 100 foot levels. Both would require about the same number of bits to provide reasonable resolution. Thus, the data link requirements of providing vertical speed and finer altitude are comparable.

F-3. SUMMARY AND CONCLUSIONS

The current ATCRBS system provides altitude reports quantized in hundreds of feet. The proposed DABS system also provides this same quantization for reported altitude. Some improvement in the ability of a separation assurance system element to protect against broken altitude clearances can be realized by providing finer altitude quantization or providing the vertical speed of the aircraft to the ground system. With either of these improvements, En Route Conflict Alert could provide about four seconds of earlier warning in cases of violation of altitude clearances. If the en route system were to use a four second scan period instead of a 12 second scan period, an average of four seconds earlier warning in cases of broken clearances could be provided. The improvement from increased data rate is independent of, and additive to, the improvement gained from eliminating altitude quantization or providing vertical speed. Thus, a total of eight seconds extra warning time could be gained in the current Conflict Alert in cases involving broken altitude clearances. Where the current Conflict Alert provides sufficient warning against impending conflicts resulting from broken clearances, this additional time of eight seconds makes no extra contribution to safety. Where the current Conflict Alert provides low warning times in such conflicts, these eight seconds can make a marginal contribution to providing adequate protection.

No improvement can be realized in Conflict Alert's ability to protect against broken clearances simply by adding a software feature that monitors altitude reports if the current 100 feet quantization is retained.

Providing altitude with finer quantization or downlinking vertical speed are nearly equivalent, both in terms of the gain in alert time and in terms of the demands they would place on the data link.

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3. "Aircraft Climb and Descent Characteristics", Federal Aviation Administration Order No. 7210.35, November 10, 1977.

4. "Aircraft Nomenclature and Climb Data", Controller Chart Supplement, Section 8, Federal Aviation Administration, Air Traffic Service, August 7, 1973.

5. "Rate of Climb Indicator, Pressure Activated (Vertical Speed Indicator)", Society of Automotive Engineers, Aeronautical Standard AS 394A.

APPENDIX G

DABS/ATARS MULTI-SITE DESIGN

C. F. Swett

G-1. INTRODUCTION

The existing multi-site design for the Discrete Address Beacon System (DABS) and the Automated Traffic Advisory and Resolution Service (ATARS) uses automatic coordination between adjacent sites in order to provide consistent and continuous surveillance and collision avoidance service at the boundaries between sites. Direct site-to-site ground communications between all sites which share a common boundary are used to effect this coordination. The features of the DABS/ATARS multi-site design which make use of this site-to-site communications channel are:

a) Surveillance Handoff. A DABS aircraft entering the coverage area of one sensor can be acquired by that sensor in a positive way with the aid of data provided by another sensor.

b) Primary Sensor Assignment. The sensors coordinate so that one and only one sensor at a time will be designated as the primary sensor for each DABS aircraft. Certain surveillance and data link functions are performed only by the primary sensor.

c) Remote Surveillance. One sensor can receive target report data from a neighboring sensor on a temporary basis for a particular aircraft which has experienced fading due to antenna shielding, or which has entered the cone of silence of a DABS sensor.

d) ATARS Seam Conflict Coordination. Messages are exchanged which provide for consistent resolution of conflicts in the areas (called seam areas) near the boundaries between sites.

e) Backup for Failed Sensor. A sensor uses the communications channels to recognize the failure of a neighboring sensor and to coordinate with the failed sensor or other sensors when initiating or terminating backup

service.

f) Multi-Site Uplink. ATARS or any other data link user has the option to designate a particular message as a message for multi-site uplink. When this option is exercised, the DABS sensor will transmit the uplink message to all other sensors maintaining contact with the subject aircraft and all sensors will attempt to deliver the message.

A recent study, documented in Reference 1, investigated various network architectures, transmission methods, and overall communications costs for DABS/ATARS multi-site coordination. That study showed that the current ATARS multi-site design places high requirements on the capacity of the site-to-site communications channel by requiring that ATARS conflict information be passed from one site to another in 0.3 seconds. The study suggested that significant cost savings could be achieved if the delivery time requirements could be relaxed from 0.3 seconds to 2.0 seconds. Such relief could be realized by reorganizing the high level ATARS processing.

The present ATARS logic operates on what may be called an epoch basis. At the beginning of an ATARS epoch cycle, the positions of all aircraft are adjusted to a common point in time (called the epoch time) based upon the tracked information resulting from the latest available target reports and upon the time of those reports. ATARS then searches through all aircraft in the data base for conflict pairs. When pairs are found, they are resolved on a pairwise basis. After the search is completed for all aircraft in the data base, ATARS messages are generated for uplink. The ATARS cycle is repeated every two seconds. In this scheme, the timing for ATARS processing is not driven by the scanning of the DABS sensor's antenna.

An alternative approach is to have ATARS processing operate on a fraction of the aircraft

at a time. This is a sector approach that works on all aircraft within one azimuth wedge or sector. After the sensor has delivered reports for all aircraft in a sector, ATARS tracks all aircraft in that sector. After a few sectors of delay to allow aircraft in surrounding sectors to be tracked also, ATARS searches for all conflicts involving aircraft in the subject sector (including conflicts between these aircraft and aircraft in neighboring sectors). ATARS then generates messages for all aircraft in that sector in time for the messages to be delivered when the antenna next points to those aircraft. During the period of time equivalent to the scanning of one sector, ATARS performs different functions for aircraft in several different sectors. Any one aircraft receives ATARS processing with a cycle time equal to the scan time of the DABS sensor.

The study in Reference 1 also showed that traffic levels in some areas would not seem to justify the expense of installing and leasing dedicated communications lines between some pairs of sites. It was suggested that a method of coordination between sites, using the storage and transmission of limited items of information by the transponder, be developed and evaluated. This approach could make it possible to avoid the use of ground communications channels in low traffic areas. It could also provide a backup communications method, that would eliminate the requirement to provide clstly alternate path communications for reliability.

The current study investigated the feasibility of reorganizing ATARS processing from an epoch basis to a sector basis and of developing a through-the-transponder method of site-to-site coordination. The study produced a feasibility model of a design for such a system and an indication of the impacts of implementing it on current designs and development programs. This appendix summarizes these results.

In this study to date, no attempt has been made to consider the software engineering details of

sector-oriented processing at a site. From the viewpoint of multi-site coordination, the only two important effects of sector processing are that coordination actions may occur at random times, and that more time is available for site-to-site message transfer. The investigation was therefore confined to the logical problems of coordination among a set of sites.

G-2. COORDINATION LOGIC USING GROUND COMMUNICATIONS

G-2.1 Key Features of the Logic

A key feature of the multi-site design concept developed in this study is that each site in the network is permanently assigned a four bit ID from the set (1000, 0100, 0010, 0001). A priority order is defined over this set, such that site 1000 has priority over site 0100, which has priority over site 0010, etc. In a pair of sites, the site of higher priority is said to be "dominant", the other site being "subordinate". Each site uplinks its ID every scan to every aircraft receiving ATARS protection from it. The transponder sets the corresponding bit in a site ID field, whose contents are downlinked to all sites in response to any interrogation. This site ID field is a part of the Conflict Indicator Register (CIR) used for interfacing ATARS and the Beacon Collision Avoidance System (BCAS). (Appendix C presents the ATARS-BCAS interface. It presents details of how the site ID is uplinked and how the site ID field is downlinked by the transponder.) The site ID field is cumulative so that it shows the ID's of all sites currently providing ATARS service to that aircraft by a 1 in the appropriate bit position.

The use of four site ID's does not appear to be restrictive. There is no known reason at this time why more than four sites should be providing ATARS service in a given airspace. An individual site may use more than one site ID. If it does, it will break up its total service area into a small number of subareas in which it will use a single ID. The use of site ID's will be coordinated between adjacent sites so that no ambiguity about which site is using which ID will exist at any particular point.

A service zone boundary between a pair of sites is controlled by the dominant site of the pair; the subordinate site is not aware of this boundary. An example of a set of service zone boundary definitions is presented in Figure G-2-1. In this

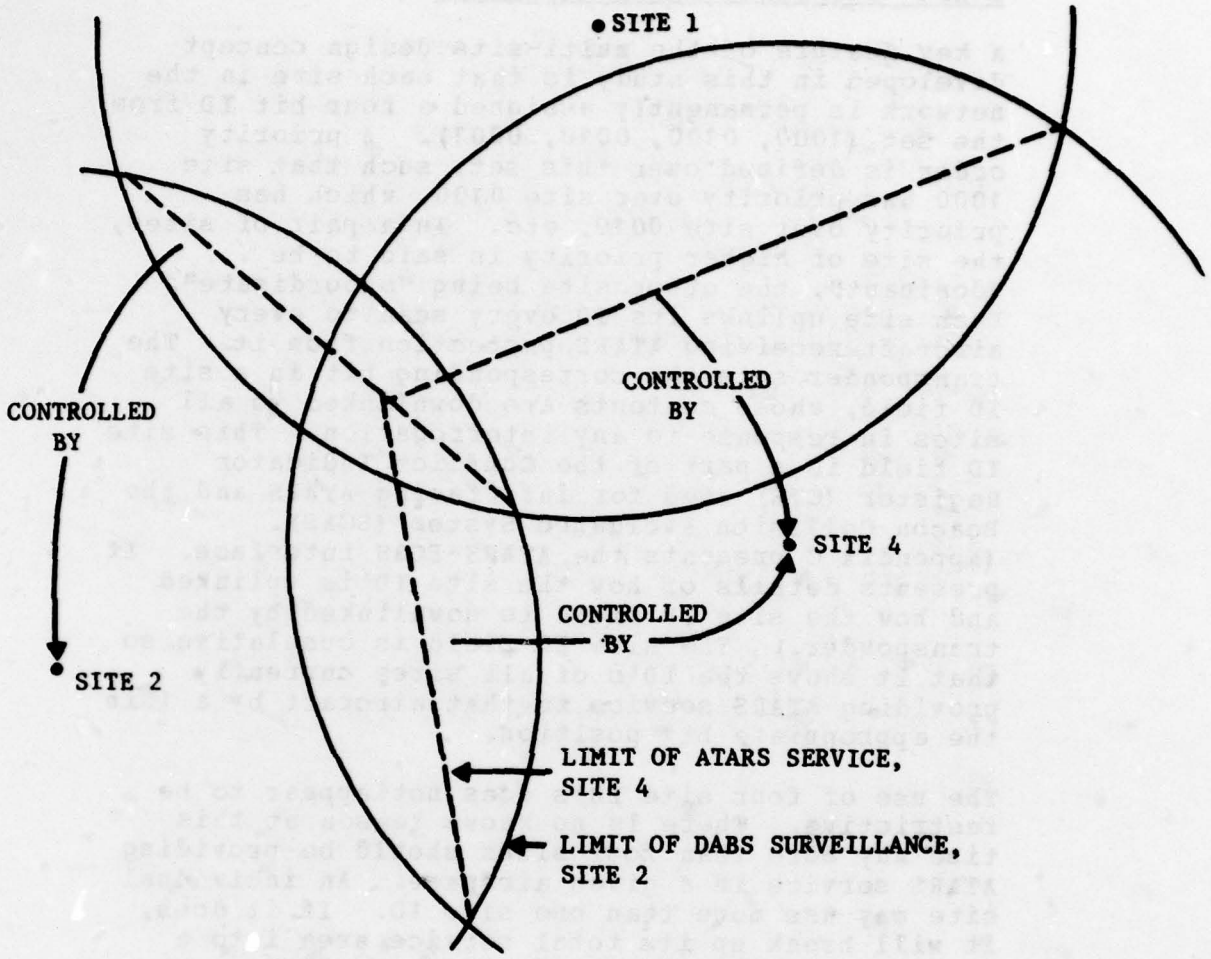


FIGURE G-2-1
SERVICE ZONE BOUNDARY DEFINITION

figure and others to follow, the limit of DABS surveillance is indicated by a circle. This boundary can actually have any shape. The same is true for the boundaries defining the limit of ATARS service.

An individual site uplinks its site ID to an aircraft each scan for as long as that aircraft is within its service zone. It resets its ID when it observes the aircraft leave the service zone across the service zone boundary. (Aircraft leaving a site's service zone across a DABS coverage floor will have that site's ID reset by a timeout clock in the transponder.) The dominant site also sends messages about these set/reset actions, before the actual uplink, to other sites in the network if those sites are connected through ground channels. The set/reset rule is suspended if the transition occurs during a conflict in which advisories have already been received by the aircraft, making this a "soft" boundary. The contents of each aircraft's site ID field are routinely recorded in that aircraft's track file by each ATARS site, so that responsibility information is available immediately if a conflict is detected.

Another key feature of the concept is that when a conflict occurs between a pair of aircraft, the highest priority site whose ID is in the site ID fields of both aircraft resolves the conflict. (The coordination logic described in this appendix is used to coordinate only resolution advisories. Traffic advisories are not coordinated.) Lower priority sites recognizing the conflict refrain from uplinking resolution advisories. For example, suppose the site ID registers of a conflicting pair of aircraft contain the data (0110) and (0111). When site 4 (0100) detects the conflict, its answer to the rhetorical question, "Which site has the highest priority site ID in both aircraft?" is, "own site". Site 4 then computes and uplinks resolution advisories for both aircraft. Site 2's answer to that same question is, "other site", and site 2 surrenders responsibility to the dominant site by not

uplinking advisories. Site 1 would not detect the conflict since it is not providing service to both aircraft. In this way, pairwise site responsibility designation is usually in steady state at the time a conflict materializes; multi-site coordination at that stage is performed only to assure compatibility of commands in multi-aircraft encounters.

Another key feature of the design concept is that responsibility for separating aircraft is designated on a pairwise (pair of aircraft) basis. Thus, a particular aircraft may receive an advisory from one site for avoiding a first threat, and simultaneously receive an advisory from a different site for avoiding another threat. Although advisories for separating a pair of aircraft may be uplinked to those aircraft by several sites (as discussed in the sequel), the single site responsible for that pair will choose the advisories. Sites are informed of each other's advisories through coordination messages received over ground lines, and through downlink of the CIR. These features are explained later in this section.

G-2.2 Examples of Site Responsibility Designation

Examples of site responsibility designation for two aircraft conflicts are presented in Figure G-2-2. In this figure, showing a three-site network, the positions of conflicting aircraft are indicated by the symbol "X". The contents of each aircraft's site ID field at the time the conflict materializes are shown next to the position symbol. These contents can be deduced from the plan view geography. (Coverage floor considerations are excluded at this point.) The circles represent DABS coverage limits, and the dashed lines between each pair of sites represent ATARS service zone boundaries. The site that will take responsibility for each conflict pair is indicated on the figure.

An interesting example of a two-site three-aircraft conflict is presented in Figure G-2-3.

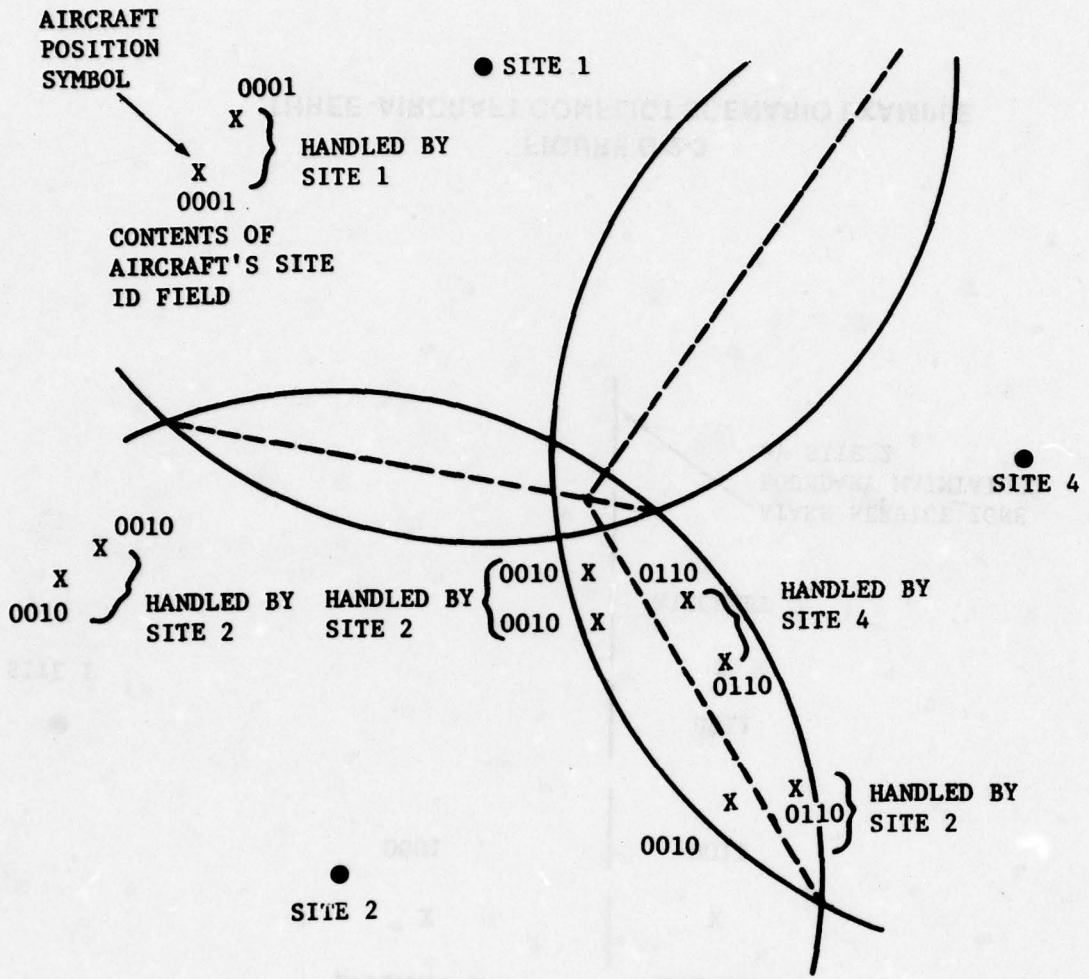


FIGURE G-2-2
EXAMPLES SHOWING SITE RESPONSIBILITY DESIGNATION FOR TWO-AIRCRAFT CONFLICTS

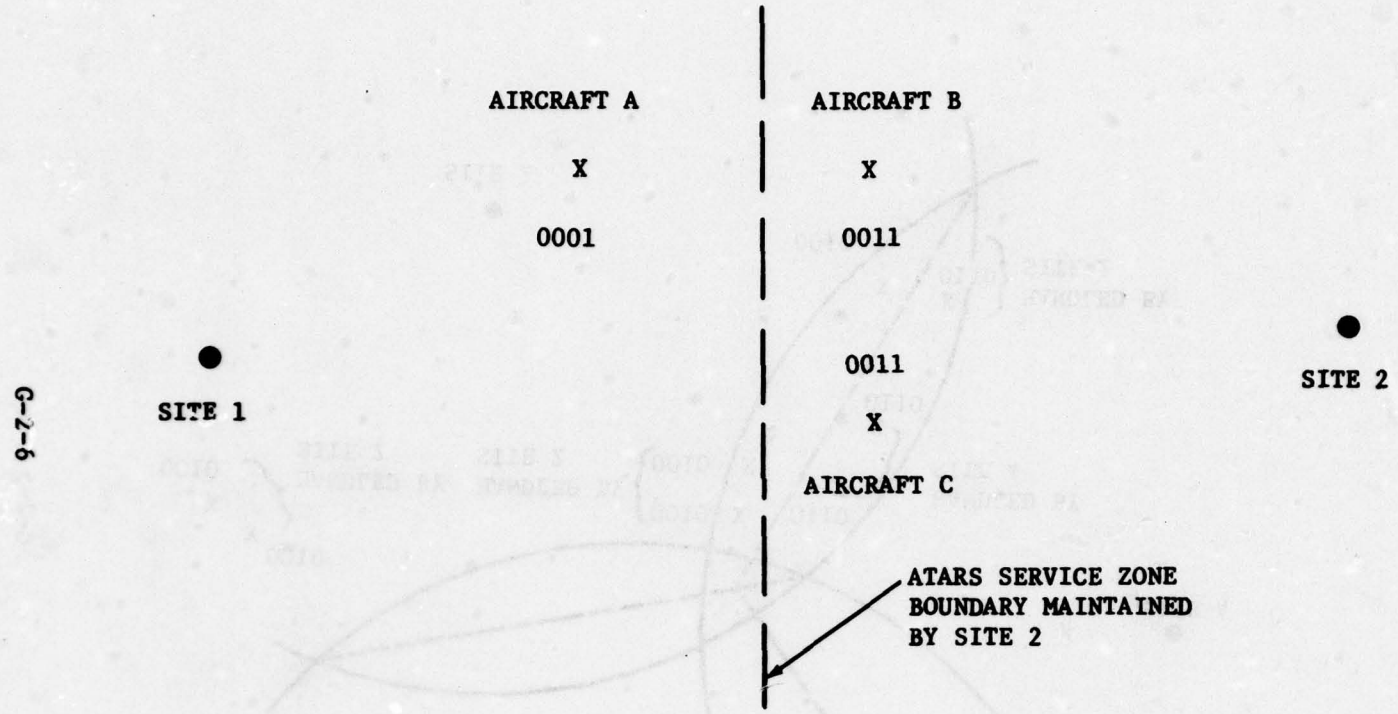


FIGURE G-2-3
THREE-AIRCRAFT CONFLICT SCENARIO EXAMPLE

The conflict between aircraft A and aircraft B is resolved by site 1, and the conflict between aircraft B and aircraft C by site 2, according to the responsibility protocol defined above. Since aircraft B will receive an advisory from site 1 for avoiding aircraft A, and also an advisory from site 2 for avoiding aircraft C, the necessity for intersite coordination to cause these advisories to be compatible is apparent.

One final example is presented in Figure G-2-4, which depicts a two-site four-aircraft conflict. When aircraft A conflicts with aircraft B, site 4 uplinks advisories to separate them. Then the conflict between aircraft C and aircraft D appears, which is managed by site 2. The A-B and C-D pairs would then be simultaneously receiving resolution advisories from site 4 and site 2, respectively. If aircraft B then conflicts with aircraft C, site 2 receives unambiguous responsibility for this pair. A compatible resolution can be developed by site 2, provided that it can be made aware of the results of site 4's resolution for the C-D pair.

G-2.3 Description of the Logic

The multi-site communication scheme is now addressed. A network of DABS/ATARS sensors fully connected by ground lines is considered.

Events related to a single conflict that occur during one sensor scan are depicted in Figure G-2-5. Time proceeds from left to right, and marks on the time line represent instants at which events occur. The left-most event is an interrogation of the first aircraft in the conflict by this site, and the right-most event is the next interrogation of that aircraft by this site. These endpoints therefore define a one-scan interval.

It is characteristic of the prototype DABS sensor hardware that ATARS may receive surveillance data as late as 3/32 scan after an aircraft is actually interrogated. Another characteristic is that

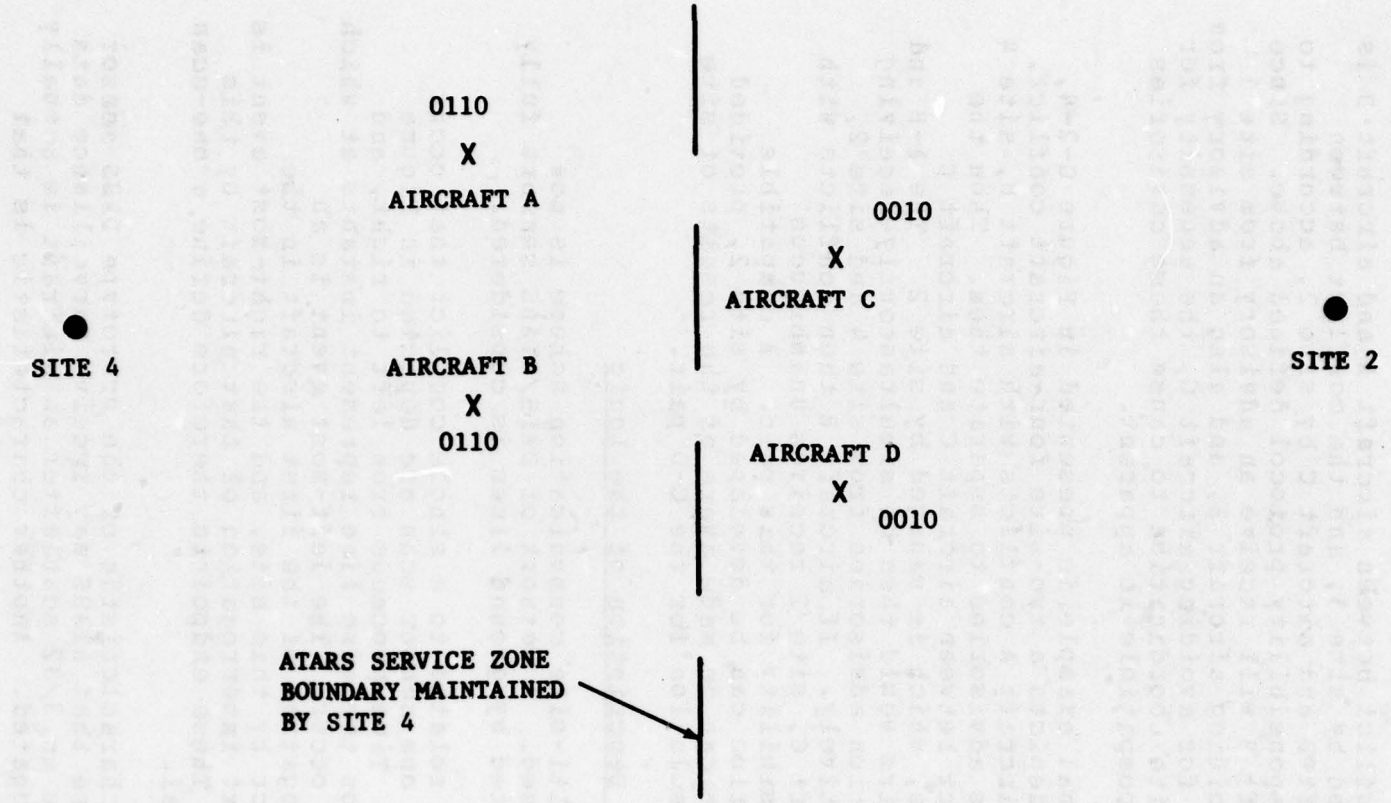


FIGURE G-2-4
FOUR-AIRCRAFT CONFLICT SCENARIO EXAMPLE

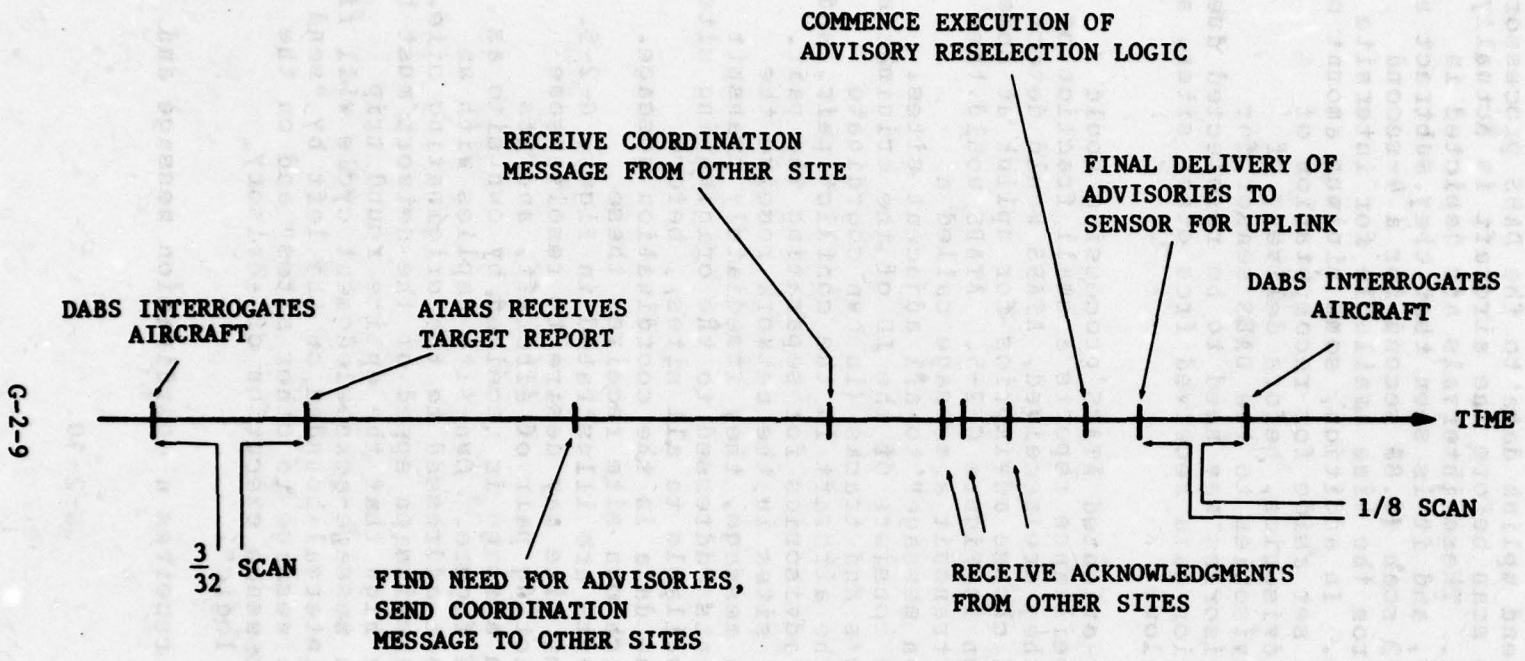


FIGURE G-2-5
SUBDIVISION OF ONE SENSOR SCAN AT A SITE

ATARS must send uplink data to the DABS processor at least 1/8 scan before the aircraft is actually interrogated. These intervals are depicted in Figure G-2-5, and it is seen that they subtract a total of 0.22 scan (0.88 second for a 4-second scan time) from the time available for intersite coordination. In addition, some minimum amount of time must be set aside for recomputation of resolution advisories, before delivery of finalized advisories to the DABS sensor for uplink. Advisories may need to be reselected due to coordination data received from other sites, as explained below.

Since sector-oriented ATARS processing would process surveillance reports a small fraction of a scan after they are received, ATARS would detect a conflict and choose advisories for uplink at some time as shown in Figure G-2-5. ATARS would then immediately transmit a message called a "coordination message" to all adjacent sites. This message consists of the ID of the originating site, the ID's and tracks (in own coordinate system) of the aircraft in the conflict pair, and provisional advisories for separating the pair. As the other sites in the network receive the coordination message, they immediately transmit acknowledgments addressed to the originating site, (but also available to all sites), before analyzing the data in the coordination message. Times at which own site receives these acknowledgments are illustrated in Figure G-2-5. Also, another site may desire to resolve some other conflicting pair of aircraft, and its coordination message is received by own site as shown in the figure. Own site replies with an acknowledgment addressed to the originating site. The data transmission speed of the network must be sufficiently high that the entire round trip coordination message-acknowledgment cycle will fit within the interval bounded on the left by "send coordination message to other sites" and on the right by "commence execution of advisory reselection logic".

When a site receives a coordination message and

replies with an acknowledgment message, it analyzes the coordination message data, setting up a conflict table or pair record if necessary. Each pair record at a particular site will indicate the ID of the site managing that pair, be it own site or a remote site. When own site desires to separate a pair of aircraft and one or both of the aircraft are already receiving advisories from any site, those advisories, which are recorded in the pair records, are used as constraints in selecting the new advisories. Own site then transmits the provisionally selected advisories to the other sites in a coordination message, and may change them based on coordination messages received, or acknowledgments not received (see below), before the advisory finalization time.

G-2.4 Examples Illustrating the Coordination Logic

A convenient way to present the multi-site coordination scheme is by a series of examples. Figure G-2-6 presents time lines (time proceeds from left to right) for a two-site network, where one site desires to separate a pair of aircraft. A vertical line drawn over this figure intersects the two sites' time lines at the same instant of real time. The first event to occur is an interrogation of the aircraft by site 1, which detects a conflicting pair for which own site's tracks indicate site 1 is responsible. Site 1 selects a provisional set of advisories and sends it, together with the aircraft ID's, site 1's ID, and site 1's tracks of those aircraft, to the other site in a coordination message. Some fraction of a scan later, site 2 receives the message, sends an acknowledgment to site 1, and records the coordination message data in a conflict table. Site 1 receives the acknowledgment, finalizes the advisories, and uplinks them to the aircraft. In this simple example, site 2 did not detect any conflicting pair for which it was responsible, and so did not initiate coordination. It only responded to coordination initiated by site 1. Coordination

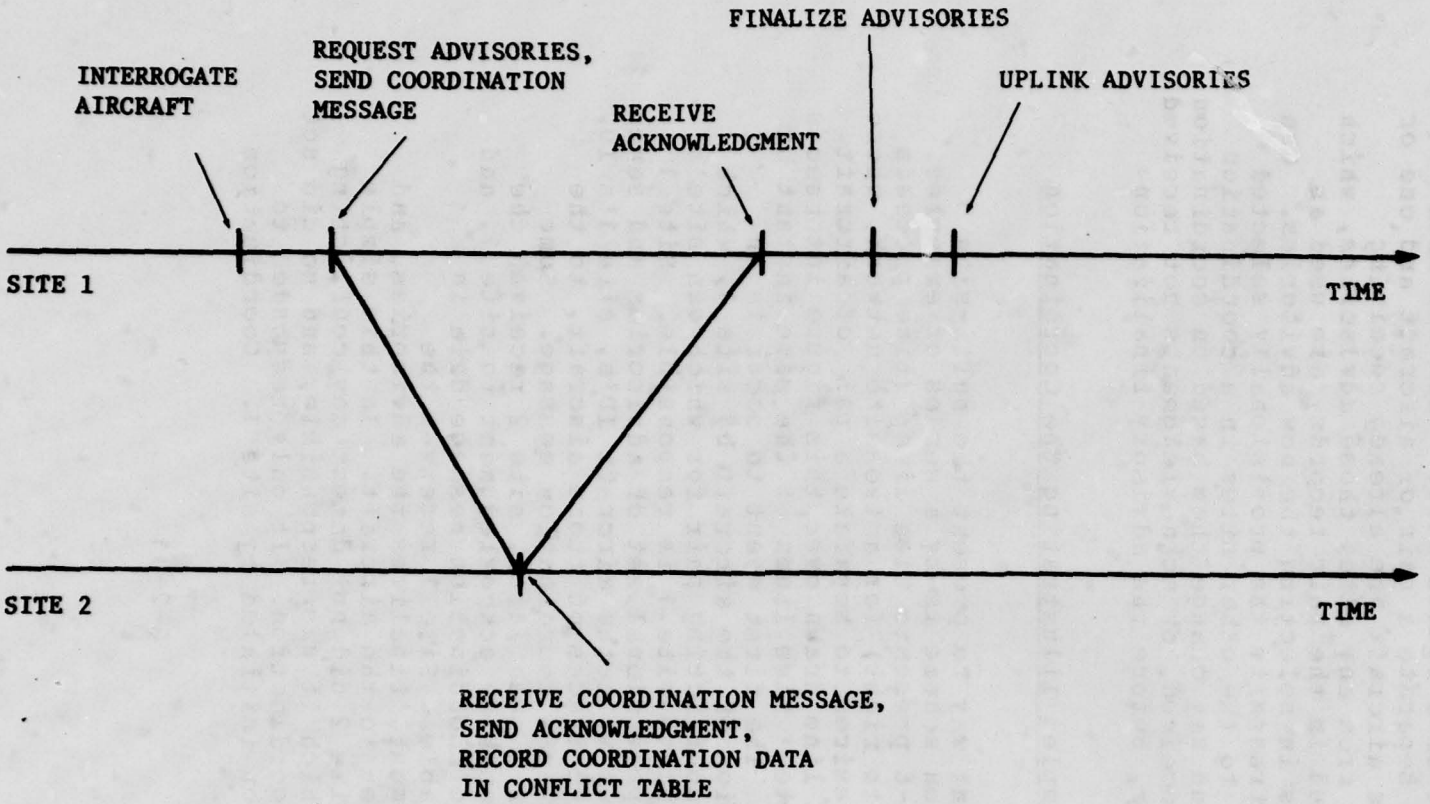


FIGURE G-2-6
EVENT SEQUENCE FOR A SIMPLE TWO-AIRCRAFT CONFLICT

thus served no particular purpose in this case. However, the need for some kind of coordination is illustrated by the following example.

A two-site, three-aircraft conflict example is presented in Figure G-2-7. Site 1 coordinates with site 2 for resolving a conflict for which site 1 is responsible, exactly as in the previous example. Several seconds later, site 2 interrogates the aircraft and detects a conflicting pair it is responsible for separating. Since this pair is part of a three-aircraft conflict, and since site 1 has coordinated for separating its pair, site 2 finds a conflict table already including one of the aircraft from the pair currently in question. The advisory that aircraft is receiving from site 1 is used by site 2 as an advisory selection constraint when choosing a provisional advisory set. That set is sent to site 1 in a coordination message, the acknowledgment is received, the advisories are finalized and they are uplinked on the next interrogation. This example event sequence is a favorable one which could have been handled by a less sophisticated coordination scheme.

A similar two-site network, three-aircraft conflict example is presented in Figure G-2-8. This example is different in that the scans during which the sites detect and coordinate for their respective conflicting pairs (the "critical" scans) overlap in real time, rather than being disjoint as in the previous example. It is apparent from the figure that all necessary information is available to each site when needed.

In Figure G-2-9, the critical scan of site 2 is wholly contained within that of site 1. Such a random event could occur since antenna rotation periods are not likely to be identical, and interrogating beam directions of adjacent sites are not likely to be synchronized. Site 1 interrogates the aircraft, selects provisional advisories, and transmits them to site 2 in a coordination message. Before finalization, however, site 1 receives a coordination message

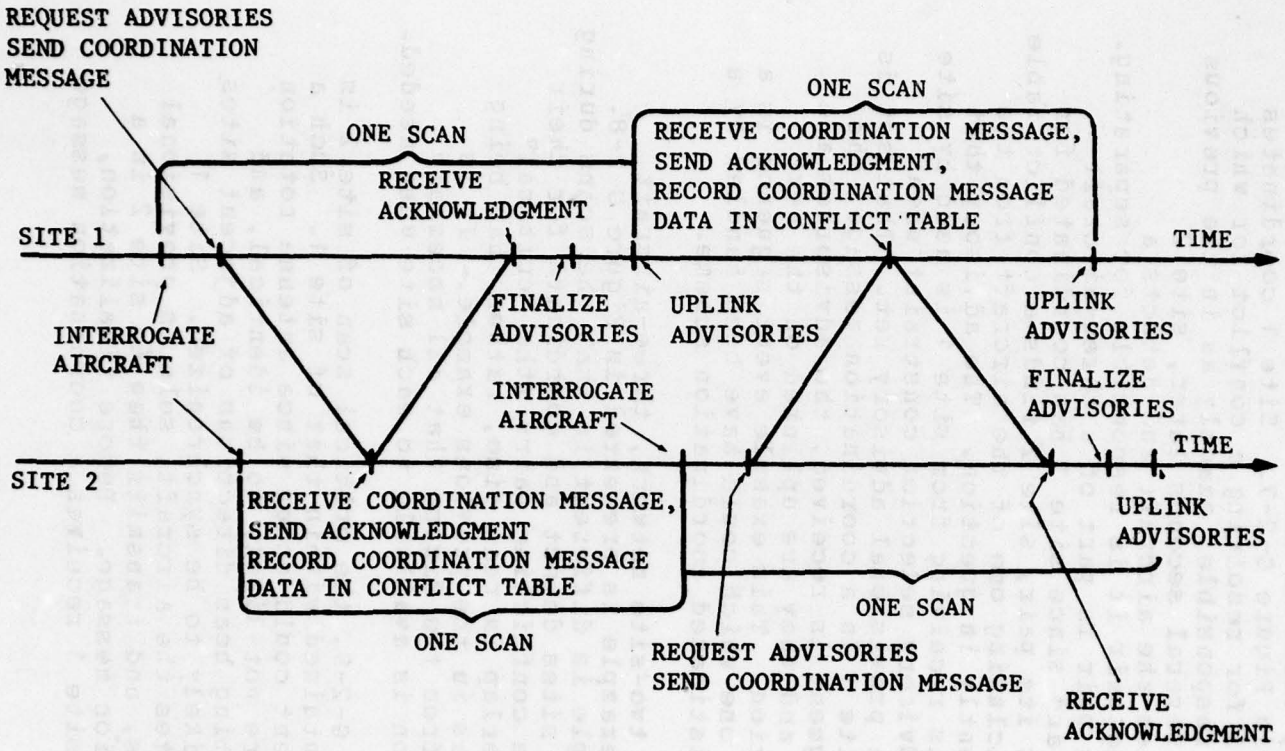


FIGURE G-2-7
EVENT SEQUENCE WHEN CRITICAL SCANS DO NOT OVERLAP

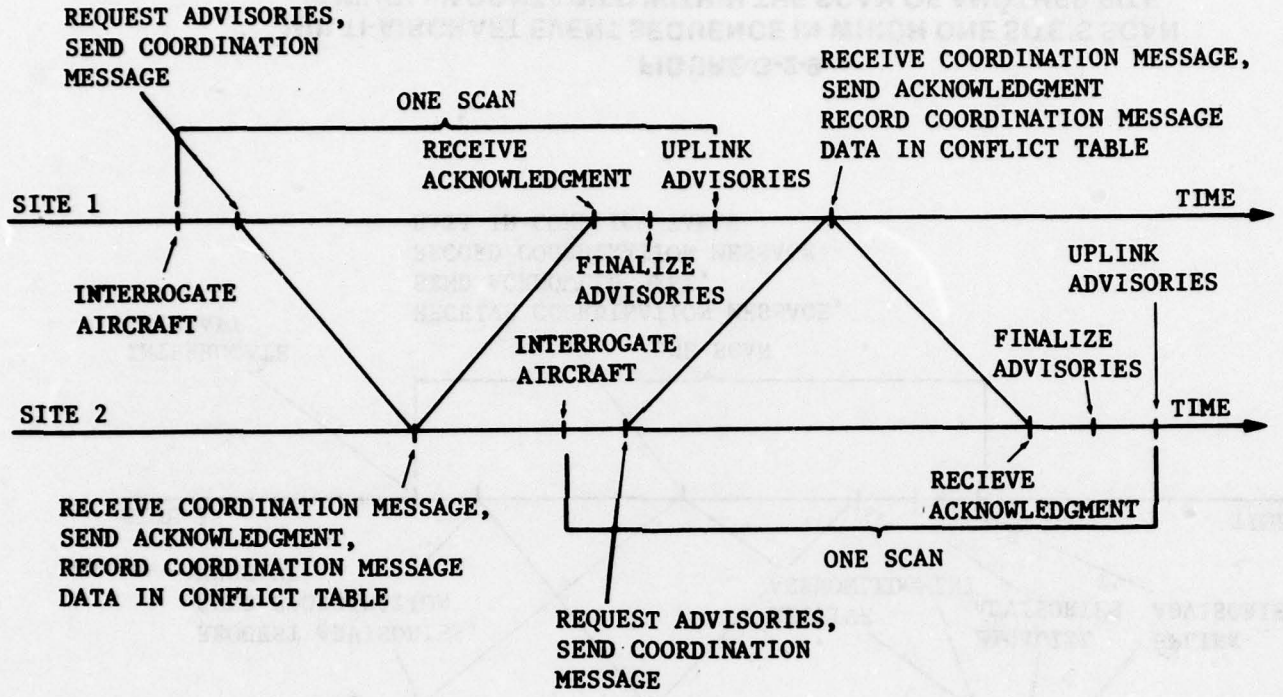


FIGURE G-2-8
EVENT SEQUENCE FOR OVERLAPPING CRITICAL SCANS

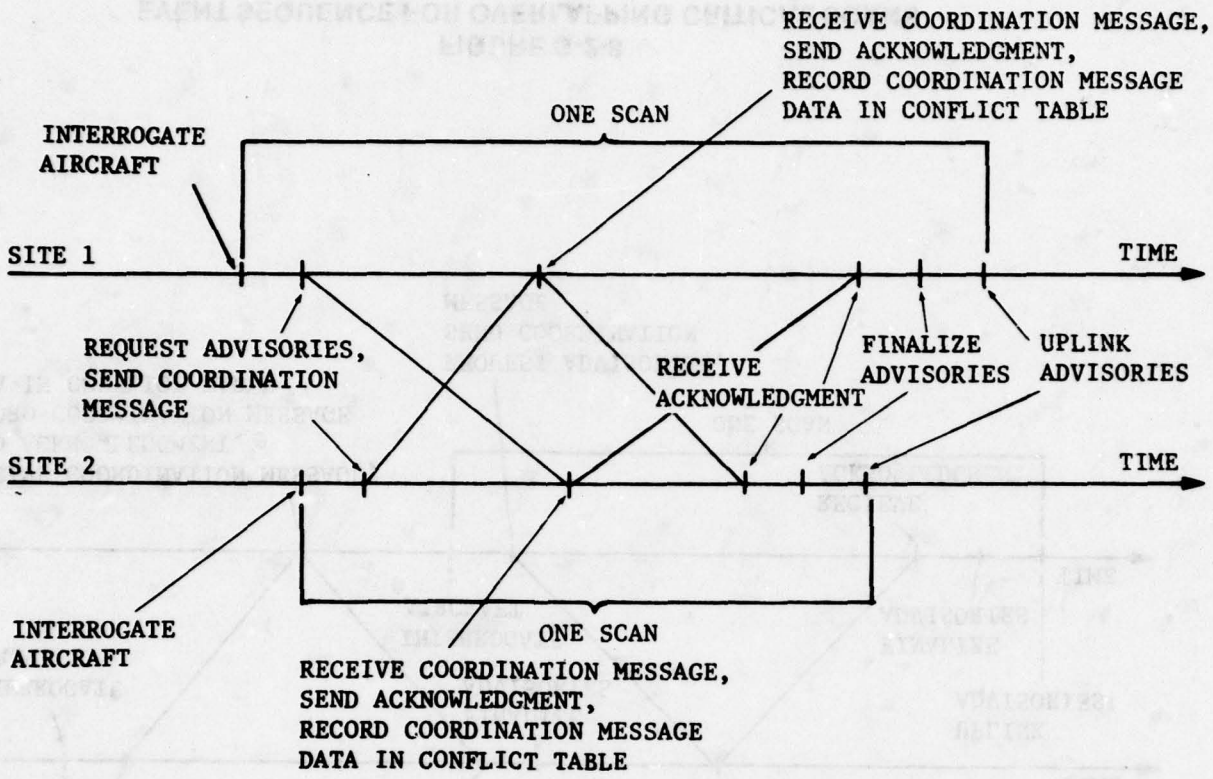


FIGURE G-2-9
MULTI-AIRCRAFT EVENT SEQUENCE IN WHICH ONE SITE'S SCAN IS WHOLLY CONTAINED WITHIN THE SCAN OF ANOTHER SITE

from site 2. This coordination message includes an advisory for the aircraft common to both pairs, which is incompatible with the advisory site 1 had provisionally selected for this aircraft. Site 1 detects this incompatibility, and invokes the priority order defined over the set of site ID's to determine which site must alter its provisional advisory set to establish compatibility. Being the subordinate site, site 1 reselects advisories. They are then finalized and uplinked. Note that the original provisional advisories were never delivered to the aircraft, so no reversals of existing advisories were involved in reselecting the advisories. Site 2 goes through an identical event history, except that it finds itself to be the dominant site, and does not alter its provisional advisories to establish compatibility. This example is more difficult to coordinate than the others, revealing the utility of the site ID priority order.

Since coordination actions can occur at random times, it is possible for a coordination message to be received by a site after execution of its own reselection logic has commenced but before uplink. Such a situation is illustrated in Figure G-2-10, where site 1 would otherwise be required to alter its set of advisories in the face of incompatibility. Site 1 replies to the coordination message from site 2 with a second type of reply called a "network confirmation". This message informs site 2 that the reason it did not receive an acknowledgment from site 1 was not that the lines had failed, but that site 1 could no longer observe the priority order because execution of the reselection logic had commenced. When confronted with this situation, site 2 must violate the priority order and change its provisional set of advisories, if necessary to establish compatibility. Site 1 will hold site 2's coordination message in a buffer and analyze it after uplink. When it does so, it will find that an incompatibility existed, and that site 2 was forced to alter its set of advisories. Since site 1 will have site 2's tracks of the aircraft involved (sent in the coordination message), and

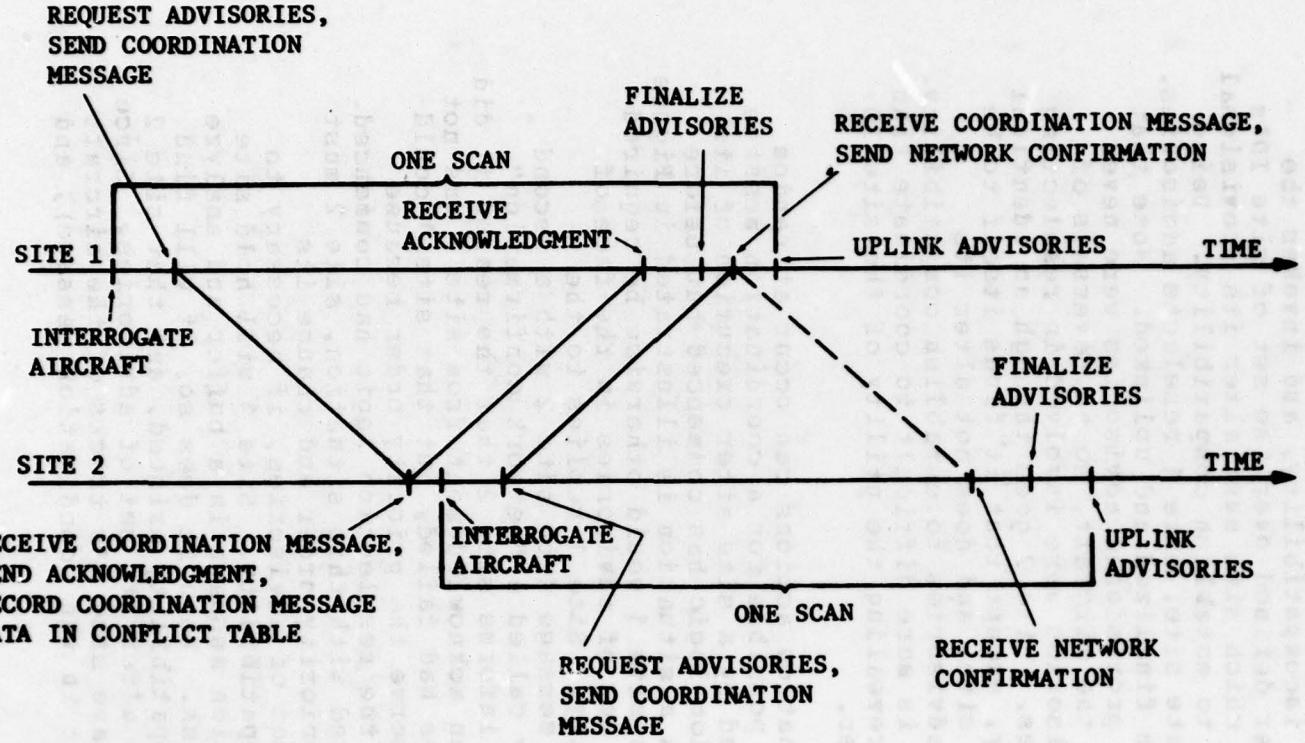


FIGURE G-2-10
MULTI-AIRCRAFT EVENT SEQUENCE IN WHICH COORDINATION MESSAGE ARRIVES AFTER ADVISORIES HAVE BEEN FINALIZED

since all sites would have identical multi-aircraft reselection logic, site 1 can deduce the new set of advisories chosen by site 2. This is recorded by site 1 in the appropriate conflict tables and used if a new pair of aircraft should shortly thereafter require advisories.

The last example (Figure G-2-11) concerns a three-site network coordinating a four-aircraft conflict in which each site has resonsibility for at least one conflict pair. In this example, the critical scans of all sites overlap in real time. The specific actions performed by site 1 have been omitted from the figure for the sake of clarity. The provisional advisories selected by site 2 and site 4, for the aircraft common to their respective pairs, are incompatible. Invoking the priority order, site 2 alters its provisional advisories and site 4 leaves its provisional advisories as they are. Meanwhile, site 1 needs to know what constraints to observe in selecting advisories for its pair. This site has the following information: provisional advisory sets and tracks sent from sites 2 and 4 in their coordination messages, the fact that these provisional sets are contradictory, and the site ID priority order. Site 1 can therefore deduce that site 2 will alter its provisional advisory set since it is subordinate to site 4. Having site 2's tracks for the aircraft involved, and having the same multi-aircraft advisory reselection logic as site 2, site 1 can also deduce the new set of advisories chosen by site 2. This example illustrates the considerable capability of this approach to multi-site coordination.

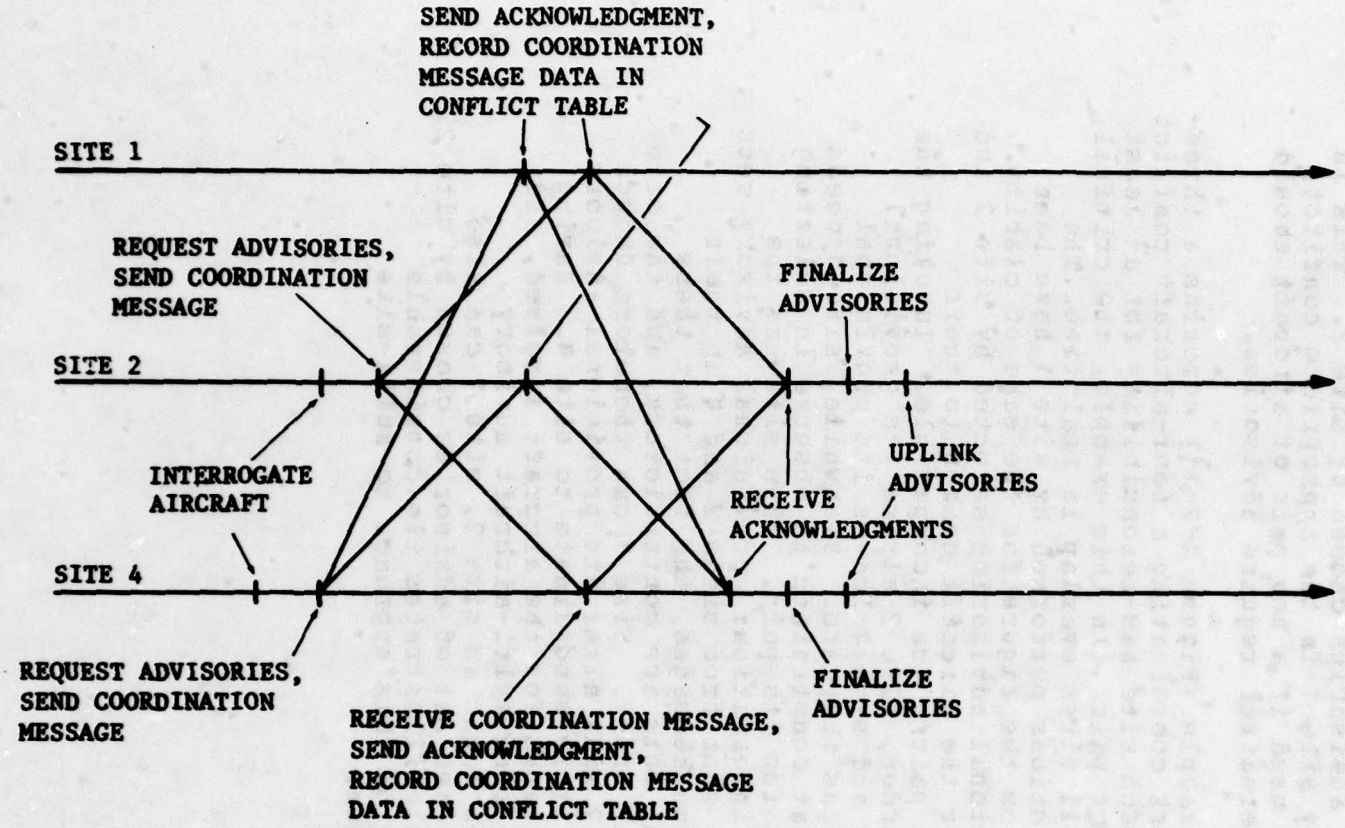


FIGURE G-2-11
EVENT SEQUENCE FOR MULTI-AIRCRAFT CONFLICT INVOLVING THREE SITES

G-3. COORDINATION THROUGH-THE-TRANSPONDER

The through-the-transponder method of coordination has received some attention in the past, under the restriction that communications were limited to DABS surveillance interrogations and replies (short messages of 56 bits). Only a few spare bit positions in these messages were available for holding coordination data, resulting in performance deficiencies in various multi-aircraft, multi-site situations. This restriction was relaxed in the present study, allowing the use of long DABS interrogation and reply messages (112 bits). The DABS formats have unused capability which can support long messages for this purpose. This section presents the feasibility model that was derived for through-the-transponder coordination.

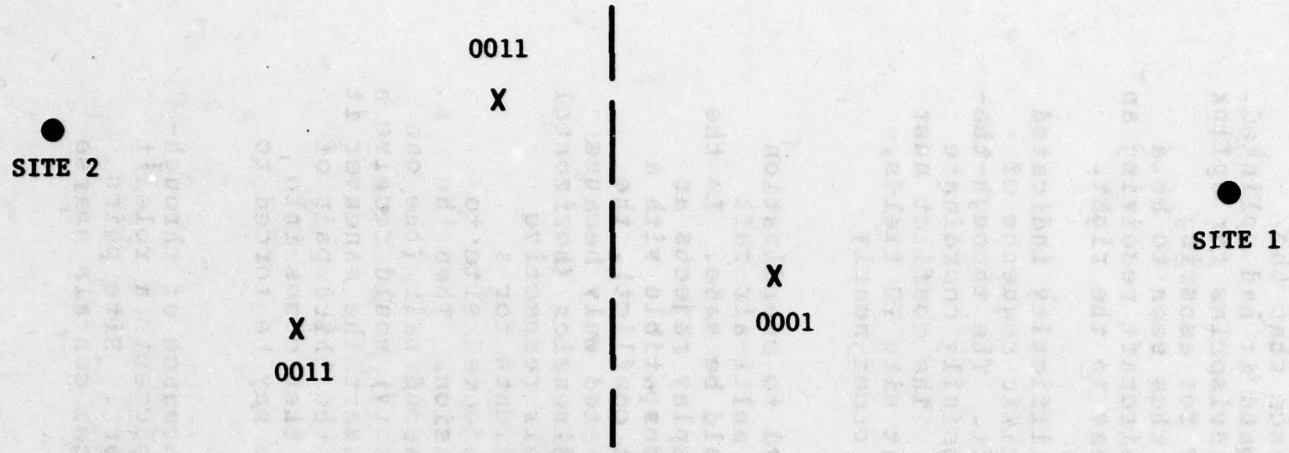
Through-the-transponder coordination uses the same site ID set, priority order and service zone boundary definition as the ground lines method. Each site sets the corresponding site ID bit in each aircraft currently receiving ATARS service from it, and the site ID field is downlinked in the response to any DABS interrogation. ATARS stores the site ID field in the local track file corresponding to the particular aircraft. Uplinked advisories are accompanied by the aircraft ID's of the threats stimulating them, and this data can be stored in the CIR. Any advisories an aircraft is receiving are downlinked to all sites, including the corresponding threat ID's. In response, each ATARS site sets up pair records or conflict tables as needed. These are available immediately if one of the aircraft involved enters a new conflict for which own site is responsible. The existing resolution advisories are used as constraints in selecting advisories for the new conflict.

In the event of site failure, neighboring sites reconfigure their service zones to extend protection into the failed site's airspace. One obvious approach to triggering the backup mode for these neighboring sites is by a command manually

entered from the responsible ATC facility.

An automatic triggering of the backup mode might be considered as an alternative. During site commissioning, a region of airspace deep within a neighboring site's service zone can be mapped and read into the ATARS software as adaptation data. In real time, the site can periodically test the site ID fields of aircraft within that airspace, for the presence of the neighboring site's ID. If it is absent from the site ID fields of several aircraft, it can be inferred that the neighboring site has failed, and own site can reconfigure its service zone boundaries (if own site were the dominant of the pair) to include the failed site's service region. If own site was the subordinate of the pair, reconfiguration would occur naturally with no specific actions required. While in the backup mode, the test airspace can still be monitored for the reappearance of the failed site's ID, which would indicate that the failed site has become operational again. Own site would then reconfigure to its normal service zone boundaries.

From this description, it can be seen that the through-the-transponder coordination method is logically similar to the ground lines method. The difference is that coordination actions are constrained to occur at discrete instants of time (the times of interrogation/reply between a site and an aircraft), rather than on a time continuum. Since the sites cannot confer with each other before the actual uplink of advisories, full continuity of advisories is not assured for all possible event sequences. An example is presented in Figure G-3-1, which shows a two-site, three-aircraft conflict. The aircraft pair whose site ID fields both contain 0011 is to be separated by site 2, and the aircraft pair whose site ID fields contain 0011 and 0001 is to be separated by site 1. The aircraft in the center of the encounter will receive advisories from both sites. As explained in the figure, if site 2 sends an advisory to this aircraft immediately before site 1 sends one, site 1 will not have the information



EVENT SEQUENCE

- ALL CLEAR
- SITE 2 UPLINKS ADVISORIES TO ITS PAIR
- SITE 1 UPLINKS ADVISORIES TO ITS PAIR WITHOUT YET RECEIVING DOWNLINK OF COMMON AIRCRAFT'S CIR

POSSIBLE SOLUTION: TRANSPONDER LOGIC TO REJECT NEW ADVISORIES IF INCOMPATIBLE WITH PRE-EXISTING ADVISORIES

FIGURE G-3-1
VULNERABILITY OF THROUGH-THE-TRANSPONDER COORDINATION

necessary for assuring compatibility before uplink. A possible solution to this problem is to have logic in the display which rejects advisories if they are incompatible with pre-existing advisories. Since the CIR data would be downlinked, the site could deduce that the aircraft had rejected the command it had uplinked. The site could then reselect advisories for uplink on the next scan. The penalty for assuring compatibility in this case is thus seen to be a one-scan delay in the middle aircraft receiving an advisory for avoiding the threat to the right.

It should be noted that this difficulty indicated above happens only with a specific sequence of events involving three aircraft. The through-the-transponder logic would successfully coordinate most three-aircraft conflicts. The conflict must involve aircraft with different site ID fields, and two of the conflicts must occur nearly simultaneously.

Although this report is devoted to coordination logic, a brief mention of the multi-aircraft collision avoidance logic should be made. In the case when the logic in the display rejects an uplinked advisory which is incompatible with a prior advisory (three-aircraft conflict), the incompatibility could have existed only because the two sites chose the same dimension (horizontal or vertical) for resolving their respective conflict pairs. A likely candidate for a reselection rule is for the rejected site to switch to the orthogonal dimension. Then the cooperating aircraft of the second pair (the one that accepted the intial advisory) would receive a new advisory which does not thwart the maneuver it might already have begun. If the third pair of this three-aircraft situation then comes into conflict, the responsible site may be forced to reverse a prior advisory.

The similar but inferior performance of through-the-transponder coordination suggests a role it can play in a multi-site network. Site pairs whose coverage overlap airspaces contain sparse

traffic (with a very low probability of multi-aircraft encounters) can coordinate solely via through-the-transponder. Those pairs sharing dense airspaces can coordinate over ground lines. Thus, a particular site may coordinate with one neighbor using through-the-transponder communication, and with another using ground communication. The universal set of site ID's and priority order, and other logical similarities, facilitate this scheme.

As long as all DABS-equipped aircraft would have the capability to relay coordination data between sites, site pairs coordinating over ground lines could simultaneously coordinate through the transponder. Then, if the ground communications between the sites were to fail, operations could be continued and conflict resolution would be continuous during the transition from ground communication to through-the-transponder communication. With the capability of the through-the-transponder logic to provide backup coordination for temporary periods of time when the ground communications fail, it is possible to implement ground communications channels with less redundancy and reliability than would otherwise be required. Significant cost savings could be realized in following this approach.

The observation can be made that there is nothing inherent in through-the-transponder coordination that requires sector processing at the sites. If it is decided not to connect DABS-ATARS sites with ground lines at all, a level of multi-site coordination could still be accomplished through the transponder. This could be done using either the current epoch processing scheme (without the intersite message transfer routines) or using a newly developed sector processing approach. The former method would require the least software redesign.

The development of the design concept for the ATARS multi-site logic described in this appendix took account of the ATARS-BCAS interface design presented in Appendix C. The resulting design

concept is compatible with the ATARS-BCAS interface design, uses the same CIR data in the display, and uses the same air-to-ground message formats. As a result of the deliberate activity to ensure this compatibility, an approach was developed which provides for proper coordination between BCAS aircraft, between BCAS aircraft and ATARS sites, between ATARS sites communicating through-the-transponder and between ATARS sites communicating through ground lines.

G-4. SUMMARY OF DEVELOPMENT TASKS AND NEW REQUIREMENTS

This final section reiterates the new capabilities required to achieve the version of multi-site coordination discussed previously in this appendix.

G-4.1 Development Tasks

A considerable amount of development of new ATARS decision logic is necessary. The ATARS task sequencing executive and various routines need to be reorganized from epoch to sector processing. Shakedown and verification testing of the new software would follow development of the new logic. Once this has been accomplished, the actual time available within the critical scan, for site to site communication, could be measured under simulated full capacity conditions. The ground communications data rate requirements would be determined by this measure.

Detailed logic design must be undertaken to fully develop the through-the-transponder design concept presented here. The resulting logic should be thoroughly evaluated through simulation and selected flight testing. Study should then be conducted to verify the operation of the ground communications and through-the-transponder communications methods when operating simultaneously with the ATARS-BCAS interface in various kinds of encounters.

G-4.2 New Requirements

Within ATARS, a system for storing and observing service zone boundaries is needed, together with a discrete site ID and priority order logic. Track files would need to include downlinked site ID field contents, and conflict tables or pair records would need to be created in response to coordination messages and downlinked CIR data. ATARS must be able to create and decode coordination messages, ATARS acknowledgments and network confirmation messages, and use these to deduce the actions of remote sites when

provisional advisory contradictions are detected. ATARS multi-aircraft logic would need to observe prior advisories originated by other sites as selection constraints when resolving own's pairs. Uplinked advisories must be compared with CIR data downlinked in the corresponding replies, to detect instances of rejection by the aircraft of incompatible advisories (if the subject pair of sites is not connected by a ground line). A service zone reconfiguration logic to be used in the case of failure of a neighboring site is needed. An ATARS to DABS message is required for commanding the set/reset of own site ID in particular aircraft.

After the ATARS sector processing logic has been developed, the ground line network architecture must be created. The message set used in this network would include coordination messages, acknowledgments, network confirmation messages, and also indications of site ID set/reset actions for particular aircraft. The required data transmission rate for this communications network must be established.

The DABS transponder and the ATARS display would need to be augmented to include the CIR data and the protocol for updating it. These requirements are the same as those to support the ATARS-BCAS interface. They are described fully in Appendix C.

REFERENCES

1. Golden, J. F., "Multi-Site Communication Methods for DABS-IPC", The MITRE Corporation, McLean, VA, MTR-7467, December, 1977.

APPENDIX H

ABBREVIATIONS AND ACRONYMS USED IN THE APPENDICES

APPENDIX H

ABBREVIATIONS AND ACRONYMS USED IN THE APPENDICES

AIM	Airman's Information Manual
ARSR	Air Route Surveillance Radar
ARTCC	Air Route Traffic Control Center
ARTS II	Automated Radar Terminal System Model II
ARTS III	Automated Radar Terminal System Model III
ATARS	Automated Traffic Advisory and Resolution Service
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
BCAS	Beacon Collision Avoidance System
bps	Bits per Second
CIR	Conflict Indicator Register
CPU	Central Processing Unit
CTS	Central Track Store
DABS	Discrete Address Beacon System
db	Decibel
EPROM	Erasable Programmable Read Only Memory
ER	Engineering Requirement
FAA	Federal Aviation Administration
FPM	Feet per Minute
g	Acceleration of Gravity
ID	Identification

IFR	Instrument Flight Rules
IPC	Intermittent Positive Control
IPD	Intruder Position Data
LINCON	Linear Conflict Predictor Module of Terminal Conflict Alert
mc	Megacycle
MFMAMS	Module for Maneuvering and Maneuver Sensitive Aircraft, A Module of Terminal Conflict Alert
MTBO	Mean Time Between Outage
NADIN	National Airspace Data Interchange Network
NAFEC	National Aviation Facilities Experimental Center
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
nmi	Nautical Mile
PROCON	Proximity Conflict Predictor Module of Terminal Conflict Alert
PROM	Programmable Read Only Memory
PWI	Proximity Warning Indicator
RAM	Random Access Memory
ROM	Read Only Memory
TCA	Terminal Control Area
VFR	Visual Flight Rules
VSL	Vertical Speed Limit